COMMONWEALTH OF AUSTRALIA

Council for Scientific and Industrial Research

BULLETIN No. 41

Studies concerning the so-called

BITTER PIT OF APPLES IN AUSTRALIA

With special reference to the variety "Cleopatra"

By

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Report of co-operative work carried out by the Department of Agriculture of Western Australia and the Council for Scientific and Industrial Research

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BITTER PIT OF APPLES IN AUSTRALIA—BULLETIN 41.

ERRATA.

Page	24	Description of figure, For Camera lucida x 220 read Camera lucida x 150.
,,	31	Line 9, for (Fig. 49, p. 485) read (49, p. 485).
,,	35	Description of figure. For Camera lucida x 63 read Camera lucida x 45.
,,	38	Line 7, for Barker (68) read Barker (see p. 82).
,,	43	Line 6, for 54, 5 read 38, 15. Line 15, for 38, 15 read 54, 5.
,,	44	In table, for 289 apples read 298 apples; for 258 apples read 158 apples; for 22/2/27 read 23/2/27.
,,	49	Under Fifth Picking, for Figs. 28 and 29 read Figs. 25 and 26.
,,	52	In table, for 13.2.28 read 13.3.28.
,,	54	Line 27, for (43.68) read (see pages 45.82).
,,	61	Table 7, 3rd line, for 20th April read 23rd April.
,,	64	Line 4, for "detailed" read "detached".
,,	68	Last line should read "towards the development of pit by reducing the total amount of water".
,,	87	Fig. 23, 2nd line, for "cell" read "cells".

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FIG. 1.—SEVERE STORAGE PIT ON CLEOPATRA.
(Note deep chocolate-brown colour of many of the pits.)

FIG. 2.—BLOTCHY CORK ON CLEOPATRA.
(Note the mottled deep-green and brown irregular blotches disfiguring the surface.)

[*Frontispiece.*

PREFACE.

This Bulletin describes investigations initiated and carried out by the Western Australian Department of Agriculture. At a comparatively late stage, the Council assisted by providing the services of an investigator (Mr. H. A. Pittman) to work under the direction of the departmental officer (Mr. W. M. Carne) in charge of the whole investigation.

The Bulletin is of a somewhat preliminary nature. Arrangements have been made for a continuance of the investigations as a co-operative piece of work between the Department and the Council. This further work will also be carried out by Mr. Carne, who has recently been appointed as one of the senior plant pathologists of the Council's Division of Economic Botany, which is under the general direction of Dr. B. T. Dickson.

CONTENTS.

Studies concerning the so-called BITTER PIT OF APPLES IN AUSTRALIA; with special reference to the variety Cleopatra.

I. INTRODUCTION.

"Bitter pit," in the sense in which the term is used by growers and investigators in Australia, ranks with codlin moth (*Cydia pomonella*) and scab (*Venturia inequalis*) as one of the most serious diseases of apples in the Commonwealth, both in the orchard and in store. As the two latter pests are not established in Western Australia, "bitter pit" is, in that State, undoubtedly the most important disease with which apple growers have to contend. It would appear from the published information that, as an orchard disease, it is of greater importance in Australia than elsewhere. Since the first record of its occurrence by Cobb (10) in 1892, the disease has received much attention in Australia; the work of McAlpine (42-48) being especially notable. Little, however, has been discovered in the way of practical control. McAlpine (46, 47) found that heavy pruning tended to increase the amount of "pit" developing on the trees. This has been generally recognised by growers, and the minimum of pruning is practised on varieties, such as Cleopatra, which are liable to severe attack in the orchard. McAlpine (47-48) claimed that immediate cold storage at non-fluctuating temperatures would control the disease in store. Smith (55), as a result of experiments conducted in Tasmania in 1926, tentatively recommended that later picking, combined with prompt refrigeration, should be adopted for the prevention of "pit" development in overseas shipments. This has not been generally adopted, though refrigeration soon after picking is generally accepted as desirable. Some individual growers, however, working on their own observations, have adopted later picking on the grounds that it results in better quality in the fruit and allows pit-liable apples to develop the trouble before picking.

Smith's conclusions were supported by Wickens and Carne (62), who further took the stand, tentatively suggested by Smith, that the development of pit in stored apples is definitely related to the maturity of the fruit when picked.

A review of the published data concerning bitter pit, and of theories as to its origin, revealed much confusion and many contradictions. It became clear that much of the confusion undoubtedly arose from an absence of fundamental data. The problem, or problems, awaiting solution, at least in Australia, had never been clearly defined. In

other words there appeared to be lacking a clear definition as to what was meant by the term "bitter pit." It was therefore decided in the present investigations to concentrate on the following points:—

1. Whether "bitter pit," in the sense used in Australia, comprised more than one disease. If so, whether diagnostic characters could be found for the recognition of the several diseases.

2. What is the earliest stage of maturity at which Cleopatra apples, if picked, will develop, in ripening, good commercial qualities? In other words, when is the Cleopatra apple no longer immature in the commercial sense? How may the stages of maturity be recognized?

3. To obtain data on the ripening of apples.

4. To check the conclusion of Wickens and Carne that pit development in apples, in ordinary or cold storage, is definitely related to premature picking. Subject to the confirmation of this correlation, to ascertain the earliest stage of maturity at which Cleopatra apples may be picked without subsequent pit-liability.

Personnel.—This work was originally undertaken by the senior author and his assistant, Mr. H. G. Elliott. Shortly after a commencement had been made, the Council for Scientific and Industrial Research, through Dr. B. T. Dickson, Chief of the Division of Economic Botany of the Council, made the services of Mr. H. A. Pittman, B.Sc.Agr., available for the work for a period of six months.

Mr. G. W. Wickens, Superintendent of Horticulture, who was keenly interested in the investigations, collaborated in the field work, assisting in the picking experiments, providing affected fruit from various sources, and placing his extensive practical knowledge at our disposal.

Material.—For the main storage experiments, it was decided to use the variety Cleopatra because of its reputation as the most "pit"-liable, both in orchard and store, of the commercial export varieties in this State. Cleopatra is also known in Tasmania as the New York Pippin, but is distinct from the New York Pippin of Downing (44) and Hedrick (29). It is generally considered to be the Ortley of American literature (44).

The Cleopatra is a mid-season, soft-fleshed fruit, usually oblong or ovoid-conic in shape, with a thin skin pale-yellow to lemon-yellow when ripe. The calyx tube is very open and the carpels are very liable to pull apart, and to develop woolly stripe in their walls. It is very subject to mouldy core and particularly to bitter pit. Losses of 25 per cent. to 30 per cent. from "pit" in the orchard are not uncommon. A good dessert and culinary apple, which sells well on the local and European markets, it is also outstanding as a regular and heavy cropper; a fact that accounts for its popularity amongst growers in spite

of its liability to disease. It does not hang well when ripe. The usual picking season in this State extends from about the middle of February to about the middle of March.

The Western Australian apple crop of 1927-28 was much below normal. Owing to the light setting and the inevitable large size of the fruit, it was feared that the results obtained from picking would be complicated by seasonal effects. It is generally recognized (43,64) that light crops and large fruit are particularly liable to "pit." It was therefore decided to use, for the main picking tests, trees carrying as near as possible normal crops. Mr. Wickens was fortunately able to find these in the Illawarra orchard at Karragullen, in the Darling Ranges, sufficiently close to allow of the work being carried out from Perth.

For laboratory work, the fruit of other varieties, as well as Cleopatra, were obtained from different parts of the State. Quite unexpectedly the occurrence of "pit" in the orchards, in spite of the small crops, was much below normal, and except on Cleopatra little could be obtained. Our material was, however, supplemented by "orchard-pitted" apples from Victoria and Tasmania, provided by the Departments of Agriculture in those States, on representations made by the Council for Scientific and Industrial Research on our behalf. These apples were secured, subject to certain conditions of inspection, &c., under special permits from the Federal Quarantine Service, the importation of apples into Western Australia being prohibited under quarantine regulations.

II. HISTORICAL.

So far as is known, the first unmistakable reference in literature to the disease now known as Stippen or bitter pit was made in Germany by Jaeger (33) in 1869, although it is quite probable that it had been in existence long before.

Crawford (16) in South Australia next described the disease, writing of it in 1886 under the heading "spotted apples." In America Jones (30) was the first to draw attention to the trouble, calling it fruit spot in 1891, and later Baldwin fruit spot or brown spot.

The now common name Stippen was apparently first applied to the disease by the apple growers of Germany; being accepted by Wortmann (64) in 1892 in his paper "On the so-called 'Stippen' disease of apples." It is quite obvious from McAlpine's account (43) that Wortmann clearly recognized Stippen as being essentially a disease of apples in storage, for after remarking that the disease is extremely common and well-known to the orchardists of Germany, he stated

that "it first appears at or subsequent to the ripening of the fruit. In Germany it only appears exceptionally when the fruit is on the tree, and then only in very liable varieties shortly before the fruit is picked, and in overgrown specimens (43)." He even came to the conclusion that the development of the disease was directly related to the diminution and final cessation of the water supply of the apple, due to the plucking and storing of the fruit.

Since Wortmann's paper in 1892, the names Stippen, Stippenflecke, Stippflecke, Stippigheit, Stippigwerden, and Stippigfleckigheit have been variously used as synonyms for the disease in German literature, while the term Stippen has been fairly widely accepted by English-speaking peoples.

The name bitter pit, by which the disease is now very commonly known, was suggested for the trouble by Cobb (12) of New South Wales in 1895. Three years previously, in 1892, in the *Agricultural Gazette of New South Wales* (10, 11), he had published illustrations and brief descriptions of two widely dissimilar "obscure" diseases. The first of these, described on page 284, is undoubtedly identical with the trouble subsequently described on the same variety (Fameuse or Pomme de Neige) in America by Mix (49) under the name of "cork." This is the disease referred to by McAlpine (44) as Cobb's "obscure disease," and where the term "obscure disease" hereafter occurs in this paper, it must be understood that this is the disease to which we refer. On page 1004 of the same volume of the *Agricultural Gazette,* Cobb figures and describes in brief, "Another obscure disease," which is identical with the trouble for which he subsequently suggested the term bitter pit. He at first clearly recognized that his original "obscure" disease was quite distinct from his "bitter pit." However in 1903 (14) owing to the fact that he could find no causal organisms associated with the diseases, and also because they seemed to present certain other features in common, such as "the stoppage of normal growth and the substitution for it of various abortions and distortions," and because of the absence of rotting following the development of the lesions, he concluded that they must probably have some common cause. Suspecting this common cause to be insect puncture, he grouped the two diseases, along with several others, under the general term "stigmonose." From the point of view of causation, therefore, Cobb had come to believe that his "obscure" disease and his bitter pit disease were probably closely related. He did not at any time make the assertion that they were the same disease or even forms of the same disease, but McAlpine (44) subsequently regarded the two troubles as being merely different forms of the one disease (see page 17, Report 1).

Following on the work of Wortmann and Cobb, Sorauer (56) wrote of Stippen in Germany in 1900, and again in 1909 in his *Handbuch der Pflanzenkrankheiten* (57). Güssow (27) described and illustrated

the disease on English apples in 1906, and gave a drawing of the affected tissue showing the presence of persistent starch grains. It is interesting to note that he records that "the injury was only detected after the apples were stored." The first reference to the disease in France was made by Delacroix in 1908 (19) under the name, "Les Points Bruns de la Chair des Pommes." Evans in 1909 (21), and Lounsbury in 1908 and 1910 (37, 38) described the disease in South Africa: Evans, in addition, made a considerable contribution to the literature on the disease from the causal point of view.

In 1911 and up to and including 1916, McAlpine in Australia (43-47) devoted great attention to the subject of bitter pit and its cause. Unfortunately, however, he used the synonyms, Stippen and bitter pit, in a very much more comprehensive manner than that in which they had been used by the two authorities directly responsible for them. Thus any non-parasitic spot disease of apples, pears, or quinces, which was not obviously Jonathan spot, became to McAlpine merely a form of bitter pit. For instance, Cobb's original "obscure" disease became—under McAlpine's greatly expanded conception—a form of "crinkle" or "confluent" bitter pit, while the bitter pit of Cobb became the "ordinary" bitter pit of McAlpine (43, p. 17). McAlpine's conception of bitter pit has been accepted up to the present without question by orchardists and later investigators in Australia.

Working on apple spot diseases in America, Mix (49) in 1916 clearly distinguished bitter pit from the type of trouble which Cobb had indefinitely designated, "an obscure disease." Both Cobb and Mix worked on the same variety (Fameuse, syn. Pomme de Neige) and from their respective descriptions and illustrations there is no doubt whatever that they were both working on the same disease: a conclusion also arrived at by Mix himself (49). The latter named this trouble "cork," and has clearly shown that the cork type of disease (which is essentially a disease occurring in the orchard) and bitter pit must be treated as two entirely distinct, although apparently related, diseases.

Summarizing the above from the Australian point of view, it will be seen that Cobb originally recognized two distinct apple diseases of unknown origin, as the "obscure" disease on the one hand, and bitter pit on the other. Later, attributing them to insect puncture, he grouped them together under the general term "stigmonose." McAlpine from 1911-1916 very definitely grouped the same two types of troubles under his expanded conception of "bitter pit." Mix in America in 1916 again separated the two groups of diseases into cork (including drouth spot), and bitter pit respectively, throwing considerable light on problems which in Australia had never been clearly defined.

Brooks and Fisher (4) in 1918, following Mix, also clearly recognized the existence of two distinct types of non-parasitic apple-spot diseases (apart from Jonathan spot), namely cork and bitter pit.

Rigg and Tiller (51) in New Zealand, in 1927, described certain non-parasitic malforming and spotting diseases of apples which they state resembled, on some varieties at least, the "crinkle" or "confluent" bitter pit of McAlpine. They recognized also close resemblances between their diseases, and those described by Mix, and Brooks and Fisher under the terms drouth spot and cork, but pointed out considerable dissimilarity from the symptoms of bitter pit, except in the very wide sense of the term used by McAlpine.

In Australia, where the term bitter pit originated, the name still has a very much wider significance than its originator himself gave it or than is accepted by authorities elsewhere.

III. NON-PARASITIC SPOT DISEASES OF APPLES IN AUSTRALIA.

To orchardists and investigators in Australia the non-parasitic spot diseases of apples fall naturally into two groups:—Jonathan spot and bitter pit (in the comprehensive sense of McAlpine). Any spot disease not obviously Jonathan spot is regarded as one of the many forms of bitter pit. It is evident that a wide difference exists between the present Australian conception of bitter pit and that obtaining in other countries. Brooks and Fisher (4) noted that apples considered by McAlpine as "crinkled" would be classified by American investigators as affected with "cork." Further the evidence from Europe and America indicates that pit is principally found in stored apples, while, on the other hand, pit to Australian workers has been largely an orchard disease. No evidence of the comparison of apples pitted on the trees with others pitted in store was available, and, indeed, following McAlpine's view (46, p. 7) that all pit originated while the fruit was on the tree, such comparison had appeared unnecessary.

The suggestion by Smith (55) definitely adopted by Wickens and
101, 102 Carne (62) that pit on the trees and pit in store originated independently necessitated a reconsideration of the problem.

Our knowledge of pit occurring on Cleopatra apples in the orchard, confirmed when affected apples were obtained in January, 1928, indicated that the disorder corresponded more closely with cork of American writers than with bitter pit as recognized in Europe and America.

It becomes obvious therefore that bitter pit, in the sense used in Australia, includes two groups of diseases, namely, true bitter pit or Stippen, as described by Cobb and Wortmann respectively, and cork.

Mix described two types of cork under the names of cork and drouth spot. Our investigations tend to show that two other types found in Australia should be included in the "cork" ensemble.

It is not suggested that a strict line of demarcation can always be drawn between these types, but they are sufficiently distinct to be readily separated by growers, and confusion is more likely to result from grouping them all under one name than by giving them distinct names.

Name Proposed.		*Earlier Name.*
1. Internal cork	..	Cork proper of Mix.
2. Crinkle cork	..	Crinkle or confluent pit of McAlpine.
3. Blotchy cork	..	None. Confused with true bitter pit in Australia.
4. Drought-spot cork	..	Superficial drouth spot of Mix.

The following table will serve to summarize the most outstanding differences between the four types of cork herein described.

TABLE I.—KEY TO THE FOUR TYPES OF CORK.

No External Discoloration.

(1) *Internal Cork.*—Large necrotic areas in the flesh often occurring close to the core. Surface typically disfigured by a large number of discontinuous elevations and depressions, giving a marked knobby or corrugated appearance.

(2) *Crinkle Cork.*—Large continuous necrotic area, or areas, in the flesh. Commonly only one, but sometimes several, very large, deep scores or depressions markedly disfiguring the surface. No external discoloration, except an occasional faint brown or pink flush on part of the depression.

Abundant External Discoloration.

(1) *Blotchy Cork.*—Large necrotic areas in the flesh, often occurring near the core. Many necrotic areas also close to the surface. Many or few of these by their presence causing the surface of the apple to be disfigured by deep-green or brown, or mottled green and brown, blotched depressions.

(2) *Drought-spot Cork.*—Lesion commonly large, but only a few layers of cells deep. No accompanying deep-seated lesions. Lesion commonly giving the suggestion of sunburn, although often taken from a shaded situation on the tree. Lesion becomes cracked and roughened when old. When first formed appears as a light-brown area in the skin, often associated with a sticky yellow ooze.

Bitter pit is, for the most part, a disease of apples originating in storage. Apparently a small amount may, however, occasionally occur while the apples are still on the trees. It is therefore obvious that the bitter pit of Cobb (the Stippen of Wortmann) divides naturally into two groups, according to whether it originates in the apples while still on the trees or not until after they are picked. For the bitter pit originating after the apples are picked the name storage pit is proposed, and for that which originates while the apples are still on the trees tree pit is suggested. Of storage pit two types have been found, distinguished by mild and severe. It must be clearly borne in mind that these latter terms apply only to the external appearance or pitting of the surface, and not to the seriousness or otherwise of the internal lesions.

We have found that as cork is formed later and later in the season, it tends to become less and less distinguishable, macroscopically and microscopically, from bitter pit formed on the trees (tree pit). That is to say, in some cases, apples apparently affected with tree pit may from a causal point of view be actually affected with late-formed (and therefore comparatively poorly-developed) cork. For this group which is a homogeneous one symptomatically, but apparently a heterogeneous one causally, the term orchard pitting is suggested. Orchard pitting therefore comprises tree pit and certain symptomatically identical cases of late-formed cork.

Table 2 shows the proposed classification of non-parasitic spot diseases of apples, based on historical grounds, while Table 3 shows a classification from the point of view of their occurrence while the apples are still on the tree, or only after they have been picked. Included in the Tables are the varieties which we have so far found to be affected.

The several types of non-parasitic spot diseases of apples are described hereafter.

TABLE 2.—NON-PARASITIC SPOT DISEASES OF APPLES IN AUSTRALIA (Based on Historical Evidence).

Showing the varieties so far found to be affected.

JONATHAN SPOT (*Scott* 1911).

A death of the superficial colour-bearing cells of the surface of the apple. The necrosis occasionally extends inwards to the pulp cells (Brooks and Fisher). Occurs chiefly after removal from the trees, but may occur to some extent before.

- Jonathan
- Spitzenberg
- Five Crown
- Newtown Pippin
- Dougherty
- Granny Smith
- Yates
- Cleopatra
- French Crab

The so-called BITTER PIT of McAlpine. (See reports 1911–16.)

Bitter pit is differentiated from Jonathan spot by being anything but superficial, and further because the necrosis extends from the pulp cells *outwards* towards the epidermis, whereas Jonathan spot works *inwards*.

CORK.

This is in part the "obscure disease" of Cobb 1892. Originates only in apples while still on the tree. It occurs in the most typical form in their early or middle life, but may occur in a less easily diagnosed form towards the late life of the fruit. Four distinct types can often be recognized as under:—

(i) INTERNAL CORK. *Cork proper* (*Mix* 1916).

- Cleopatra
- Spitzenberg
- Pomme de Neige, Ben Davis, Northern Spy, Oldenburg } Mix
- Pomme de Neige, **Cobb**

(ii) CRINKLE CORK. *Crinkle* (*McAlpine* 1911–16).

- Granny Smith
- Yellow Bellflower
- Rome Beauty
- Newtown Wonder, Rome Beauty, Five Crown, Dunn's, &c. } **McAlp.**

(iii) BLOTCHY CORK.

- Cleopatra
- Five Crown
- Sturmer
- Newtown Pippin
- Spitzenberg
- Jonathan
- Granny Smith
- French Crab

(iv) DROUGHT-SPOT CORK. *Superficial Drouth Spot* (*Mix* 1916).

- Tasma (following Water Core)
- Cleopatra
- McIntosh, Northern Spy, Ben Davis, Bellflower, Wealthy, Oldenburg, Fameuse } **Mix**

CERTAIN CASES OF LATE-FORMED CORK.

STIPPEN (*Wortmann* 1892). BITTER PIT (*Cobb* 1895).

This is essentially a disease developing in apples after picking. In small numbers, however, apples may be affected on the trees. We therefore get two divisions, one of which is tree pit—the other being storage pit.

TREE PIT. (Relatively uncommon and not of great commercial importance.)

STORAGE PIT. (Very common and economically of great importance.)

ORCHARD PITTING. (from Certain Cases of Late-formed Cork and Tree Pit)

- Cleopatra
- Granny Smith
- Five Crown
- Shockley
- Rymer

ORDINARY STORE.

MILD TYPE.

- Cleopatra
- Granny Smith
- Newtown Pippin
- Lord Nelson
- Tasma

COLD STORE.

MILD TYPE.

- Cleopatra
- Granny Smith
- Dunn's
- Jonathan

SEVERE TYPE

- Cleopatra
- Dunn's
- Delicious

TABLE 3.—NON-PARASITIC SPOT DISEASES OF APPLES IN AUSTRALIA (according to Occurrence on Tree or in Store).

- JONATHAN SPOT (*Scott* 1911) (late life of apple on tree and in storage).
  - Varieties affected—
    - Jonathan
    - Esopus Spitzenberg
    - Five Crown
    - Newtown Pippin
    - Dougherty
    - Granny Smith
    - Yates
    - Cleopatra
    - French Crab
- So-called BITTER PIT in Australia (since McAlpine 1911–16).
  - ON THE TREES.
    - CORK.
      - INTERNAL CORK.
        - *Cork proper* (*Mix* 1916).
        - Cleopatra
        - Spitzenberg
        - Pomme de Neige, Ben Davis, Northern Spy, Oldenburg } Mix
        - Pomme de Neige, Cobb
      - CRINKLE CORK.
        - *Crinkle* (*McAlpine* 1911–16).
        - Granny Smith
        - Yellow Bellflower
        - Rome Beauty
        - Newtown Wonder, Rome Beauty, Five Crown, Dunn's, &c. } McAlp.
      - BLOTCHY CORK.
        - Cleopatra
        - Five Crown
        - Sturmer
        - Newtown Pippin
        - Spitzenberg
        - Jonathan
        - Granny Smith
        - French Crab
      - DROUGHT-SPOT CORK.
        - *Superficial Drouth Spot* (*Mix* 1916).
        - Tasma (following Water Core)
        - Cleopatra
        - McIntosh, Northern Spy, Ben Davis, Bellflower, Wealthy, Oldenburg, Fameuse } Mix
    - TREE PIT.
      - CERTAIN CASES OF LATE-FORMED CORK.
      - ORCHARD PITTING
        - Granny Smith
        - Rymer
        - Five Crown
        - Cleopatra
        - Shockley
  - IN STORE (STORAGE PIT).
    - ORDINARY STORE.
      - MILD TYPE.
        - Cleopatra
        - Granny Smith
        - Newtown Pippin
        - Lord Nelson
        - Tasma
    - COLD STORE.
      - MILD TYPE.
        - Cleopatra
        - Granny Smith
        - Dunn's
        - Jonathan
      - SEVERE TYPE.
        - Cleopatra
        - Dunn's
        - Delicious

1. Jonathan Spot.

Jonathan spot was first reported by Scott (53) in 1911, a fuller report being given by Scott and Roberts (54) in 1913.

As generally used, the term is understood to apply only to a very superficial trouble, consisting of the death of small patches of the colour-bearing cells.

McAlpine (47) describes the disease as follows:—

"Jonathan spot is the name given to very shallow black or brown spots in the skin of the apple. The spots may be small and isolated and slightly depressed, but generally they form superficial dark blotches which run together into patches of varying size. The blotches usually extend all over the calyx end and middle of the fruit, while the stem end is comparatively free. If the discoloured skin is carefully removed from the underlying flesh, it is seen to be purely a skin disease, since there is no browning of the pulp cells immediately beneath, or any change in their texture. The disease is thus seen to be quite distinct from that of bitter pit, which is an internal disease, first affecting the pulp cells beneath the skin and causing their discoloration."

McAlpine only found the disease in Australia on Jonathan, but we have found it on Jonathan, Esopus Spitzenberg, Five Crown, Newtown Pippin, Dougherty, Granny Smith, Yates, Cleopatra, and French Crab.

In parts of America it appears to be most prevalent on Jonathan and Esopus Spitzenberg, but it is also commonly met with on a large number of the other varieties (32).

Contrary to the generally accepted idea that Jonathan spot is a purely superficial disease, Brooks and Fisher (4) state that—

> "Later the spots may enlarge to a diameter of 3 to 5 mm., become slightly sunken and spread down into the tissue of the apple to a considerable depth. In this latter stage of the disease rot fungi are often present. . . ."

This is confirmed by our experience.

The dead areas of the surface are usually, if not always, located around the lenticels. (Fig. 3.) As seen by us, the lesions of Jonathan spot on Jonathan and Spitzenberg apples were as follow:—

Very many irregular to regular, very shallow, but sharply depressed areas occurred on the cheeks of the fruit, and even in the calyx depressions. Many of the dead areas were little larger than a pin's head, while others measured as much as 18 by 10 mm. on the same fruits. The colour of the spots varied from a light-brown to almost black, and contrasted sharply with the rich red of the healthy portions. (Fig. 18.) The spots occurred all round the surface of the apples and extended from close to the pedicel region right down into the calyx depression. A number of the medium-sized lesions were confluent. The smaller spots, on cutting, proved to be quite superficial, but many of the larger ones extended into the pulp to a depth of 3 mm. from

the skin. Fungal rotting followed very readily after the development of Jonathan spot. (Fig. 3.) Where such infection occurred, the spots became distinctly rounded with smooth outline. No growth was obtained on potato dextrose agar from typical spots, while species of *Fusarium* and *Gloeosporium* were isolated from the rounded lesions following infection of the spots.

The most striking symptomatic difference between Jonathan spot and bitter pit appears to be that in Jonathan spot the epidermal and hypodermal colour-bearing cells are the first to be affected, and from these the disease may spread *inwards.* In bitter pit the first cells to be affected are the pulp cells, and from these the disease works outwards, so that the hypodermal and epidermal cells are the last cells to be affected. The dead areas in Jonathan spot, moreover, centre about the lenticels, whereas bitter pit areas seem to develop without any relation to the disposition of the lenticels whatsoever. Owing to these differences, and to the fact that, whenever deep-seated Jonathan spots are found, there will almost certainly be a number of quite superficial spots also present, little difficulty should be met with, in practice, in distinguishing Jonathan spot from bitter pit.

2. Cork (including Internal Cork, Crinkle Cork, Blotchy Cork, and Drought-spot Cork).

(i) Internal Cork.

According to Mix (49), cork may occur at any time during the growth of an apple, from the time when it is about ¾ inch in diameter up to the time when it is nearly mature. The disease is, however, most commonly met with from the half-grown stage onwards. It is characterized by the presence of a large number of brown, corky-looking areas scattered throughout the flesh, following closely the course of the vascular bundles. These dead, brown areas may be found irregularly arranged within the core-line, occupying the middle regions of the pulp, or lying close to the periphery of the fruit. The internal brown areas never extend outward as far as the skin, and consequently there is no browning of the surface. If the brown areas in the flesh are formed at a comparatively late stage in the life of the apple there may be no external evidence whatever, at picking time, that the apple is internally diseased. Similarly, should the apples be examined at any stage shortly after the development of the lesions, they may appear outwardly perfectly normal. However, should the development of the brown areas take place comparatively early in the life of the apple, the subsequent growth of the healthy regions of the flesh, combined with the absence of growth in the dead affected areas, may result in the surface of the apple assuming a very badly contorted or corrugated appearance. Mix found this disease in the varieties Fameuse (Pomme de Neige), Northern Spy, Oldenburg, and Ben

Davis, though chiefly in Fameuse. Cobb (10) and McAlpine (43) both found the same disease on the Pomme de Neige (Fameuse) variety in New South Wales.

The disease, as it occurs on the above varieties, can be distinguished from bitter pit or Stippen, because of the absence of surface pitting, and the fact that the internal brown areas are not more abundant in the peripheral zone of the pulp, as in the case of bitter pit, but are often situated very deeply in the flesh, sometimes lying very close to the core. The more or less corrugated external appearance of the surface, showing large elevations and depressions, when present, is, however, the most obvious point of difference between apples affected with internal cork and those affected with bitter pit. According to Mix, sometimes, "in the earliest stage of the disease, the internal brown spots are surrounded by a green water-soaked area suggestive of the well-known water-core disease. This area may even show through the skin of the fruit as a darker green water-soaked spot. This appearance is not, however, characteristic of the disease and is not found in later stages."

Brooks and Fisher (4), in describing cork, state that the brown areas in the flesh sometimes resemble the internal brown areas found in bitter pit apples, but are usually much larger in extent, more deeply seated, firmer in texture, more corky, and less spongy. During the development of the disease, reddish stains, which may gradually become water-soaked and covered with a sticky, yellow ooze, are said to appear on the surface of the apples. Later, the skin regains its normal colour, but large areas of dead, brown tissue are left in the pulp.

It will be evident from the above, therefore, that the internal, dead, brownish-coloured, corky-looking areas in the pulp never extend outward, in the cases described by Mix and Brooks and Fisher, to the surface of the fruit. In our experience with cork, however, it has been rare to find apples in which the presence of cork areas in the flesh was not associated with more or less abundant brown discoloration of patches of the skin. We have worked, however, with different varieties from those mentioned by the above writers, and herein may lie the reason for the difference in external appearance of affected apples.

To distinguish between the cases where the internal cork areas described above give no external indication of their presence by discoloration, and those where they do, we propose to call the former trouble "internal cork." Where the brown areas in the flesh extend up to and include, or almost include, the skin, deep-green or brown or mottled green and brown depressed blotches will be found disfiguring the surface. For such types of cork the name "blotchy cork" is proposed. This type of cork has not been mentioned by Mix or Brooks

and Fisher, but with us it is by far the most common form. Much of the cork-type trouble found in New Zealand by Rigg and Tiller (51) undoubtedly belongs to the section blotchy cork (cf. their figure of Sturmer apples opposite page 127).

We have occasionally found Cleopatra and Esopus Spitzenberg apples showing internal cork, but the occurrence of cork without associated external discoloration appears to be uncommon in varieties of apples grown in Western Australia.

The "bitter pit" recorded by McAlpine (43) and Carne (6) on pears is undoubtedly the internal cork of the present paper. This has been confirmed, so far as the latter record is concerned, by examination of preserved specimens collected by Carne in 1927. (Fig. 4.) McAlpine found it on Josephine, Beurre Clairgeau, Golden Beurre, Winter Bartlett, and Winter Nelis, and Carne on Beurre Bosc, Winter Bartlett, and Josephine.

(ii) Crinkle Cork.

Crinkle cork is the "confluent bitter pit" or "crinkle" of McAlpine, and is really only a special form of internal cork. Affected fruits are characterized by the presence of one or more deep scores or depressions on the surface. Where the depressions are numerous the apples are sometimes said to be affected with "pig-face" or "monkey-face." (Fig. 5.) Where only one furrow occurs, it may be found partly encircling the calyx region, or else forming a large curved groove on the cheek. Occasionally a deep score may occur near or about the pedicel region. Where a groove occurs on the cheek of the apple it may be strongly curved, or even almost circular, but discontinuous at one or two points. The general appearance of a badly crinkled apple is very striking by reason of the malformation of the surface; but, beyond a slight brown or pink flush which occasionally occurs, there is no discoloration of the surface in the depression. (See McAlpine 43.)

Internally, the lesions present the appearance of typical cork. Sometimes the cork tissue may not be very deep, but at other times it is very extensive. Quite commonly large cavities occur in the internal dead tissue. Smith, in California in 1911 (43, page 16), described and figured what McAlpine considered to have been the same trouble, under the name of "hollow apple." Brooks and Fisher (4, pages 133-4) mentioned "a special form of cork" on York Imperial, Gano, and Esopus apples called "York spot" or "hollow apple," which also appears to be identical with crinkle cork (4, Pl. 5, Fig. F.).

The disease was found by McAlpine on Five Crown (London Pippin), Annie Elizabeth, Esopus Spitzenberg, Rome Beauty, Rymer, Yates, Newton Wonder, Blenheim Pippin, Stone Pippin, Jonathan, Statesman, and Dunn's, while it has been found by us on Yellow Bellflower, Rome Beauty, and Granny Smith.

(iii) Blotchy Cork.

We have had most experience with blotchy cork on the Cleopatra variety, but the trouble has also been found by us on Sturmer, Newtown Pippin, Five Crown, Esopus Spitzenberg, Granny Smith, and Jonathan apples from Victoria, and Granny Smith, French Crab, and Cleopatra from Tasmania. These apples were obtained from the above-noted Departments of Agriculture as being "affected with 'bitter pit' on the trees."

The characteristic features of various varieties of apples affected with blotchy cork are as follow:—

Cleopatra (from Western Australia).

The variety Cleopatra is affected with blotchy cork to a greater or lesser extent every year in this State. On some trees up to 100 per cent. of the fruit may be affected, while a 25-30 per cent. loss is not uncommon. The disease may be found at least as early as January. During the present year blotchy cork, which was less in evidence than usual, was first noted the last week in January, but was then in an advanced condition. Affected apples show internal features which in many ways recall the descriptions of Mix, and Brooks and Fisher, given under the heading internal cork. Small to very large, compact, dark-brown, corky-looking areas may occur close to the surface of the fruit, in the middle regions of the pulp, or lying very close to the core. The smaller necrotic areas lying close to the skin very often show a marked tendency to become confluent, thus ultimately forming very extensive internal and external lesions. (Figs. 6 and 7.) Some of the larger lesions may be 20 mm. by 15 mm. in surface measurement, and 10 mm. deep, but very irregular in outline. Some of the smaller necrotic areas in the flesh, especially when lying just beneath the skin, may resemble those found in a similar position in apples affected with bitter pit. Usually, however, the necrotic areas characteristic of the cork disease are darker in colour, much larger, and not nearly so regular in outline as those characteristic of pit. The necrotic areas in pitted apples tend to be remarkably regular in outline, and it is a very noticeable fact that the diameter of the necrotic areas is closely approximate to the diameter of the external pits with which they are associated. In the case of cork, however, the internal brown areas are characteristically much more extensive and irregular than one would be led to suspect from examination of the external lesions associated therewith. The necrotic areas are occasionally more or less globular or cylindrical in outline, but usually they are exceedingly irregular. On this account, and because of their large size and the presence of lesions close to the core, they may usually be readily distinguished from pit lesions. As in the case of pit lesions, however,

the necrotic areas are very intimately associated with the vascular tissues. Cleopatra apples received from Tasmania were found to be affected similarly to those described above from Western Australia.

Unlike the cork of the American writers, the necrotic areas found in the Cleopatra very frequently extend outward through the hypodermal cells, eventually embracing the epidermis. This does not take place, as a rule, over the whole of the surface which overlies an extensive internal lesion, but the necrotic tissue extends outwards to the epidermis in small scattered patches. Where the necrosis has extended close, but not quite to the surface, small deep-green patches occur in the skin.

Following the development of the necrotic areas in the flesh, subsequent growth in the still healthy regions very often leads to a markedly rugose or malformed appearance being presented by the apple when viewed externally. The surface becomes disfigured by a series of more or less sudden elevations and depressions, the severity of the malformations depending on the extent of the necrotic lesions in the flesh, their closeness to the surface, and the extent to which growth has taken place in the healthy regions after the necrotic areas were formed. These depressions are mostly very irregular in outline, and may measure, in extreme cases, 30 mm. or more in length by 15 mm. or more in width. They are generally of a much deeper green colour than the surrounding healthy tissue. The deep-green colour is commonly mottled with dark-brown blotches, due to the necrotic tissue having extended in more or less isolated areas to the surface. (Frontispiece, Fig. 2.) The longer the apple has been on the tree since the development of the necrotic areas, the more extensive and numerous are the brown surface patches. Sometimes apples are found showing no brown blotches externally, but merely the deep-green, irregular depressions indicating a transitional stage between internal and blotchy cork.

The later in the life of the apple the necrotic areas in the flesh are formed, the less pronounced and numerous are the elevations and deep-green depressions on the surface. Consequently, apples affected with late-formed cork may show little malformation or discoloration of the surface. What external depressions are formed may be small and may closely resemble pit lesions. The internal appearance may also support the idea that the apple is affected with tree pit. It is impossible in some cases to differentiate between tree pit and very late-formed blotchy cork. Nevertheless, in their typical cases, bitter pit and blotchy cork are two essentially distinct and readily recognizable diseases.

Blotchy cork is a disease occurring only while the apples are still on the trees. It never originates in store. Typically it develops while the apples are still quite green and immature, and is associated with a rugose or malformed appearance, the surface being disfigured by deep-green or brown, or mottled green and brown, blotched depressions. The necrotic areas are mostly very large and confluent, and many may occur very deeply situated in the flesh, even lying against the core.

Bitter pit, on the other hand, for the most part originates in store, although it occasionally occurs during the late life of the apples on the trees. It does not lead to corrugation of the surface, but consists of definite more or less scattered, comparatively small, sub-circular to circular definite pits. The internal lesions are mostly small and never occur further than about 15 mm. from the skin. (See Figs. 1, 2, 8, and 9, showing comparison between storage pit and blotchy cork on Cleopatras.)

McAlpine's coloured frontispiece to his Second Progress Report (44) gives a perfect representation of a Schroeder apple affected with typical blotchy cork, and the adjoining Cleopatra shows bitter pit. These two figures give a good indication of the differences in the external features of apples affected with blotchy cork and those affected with bitter pit.

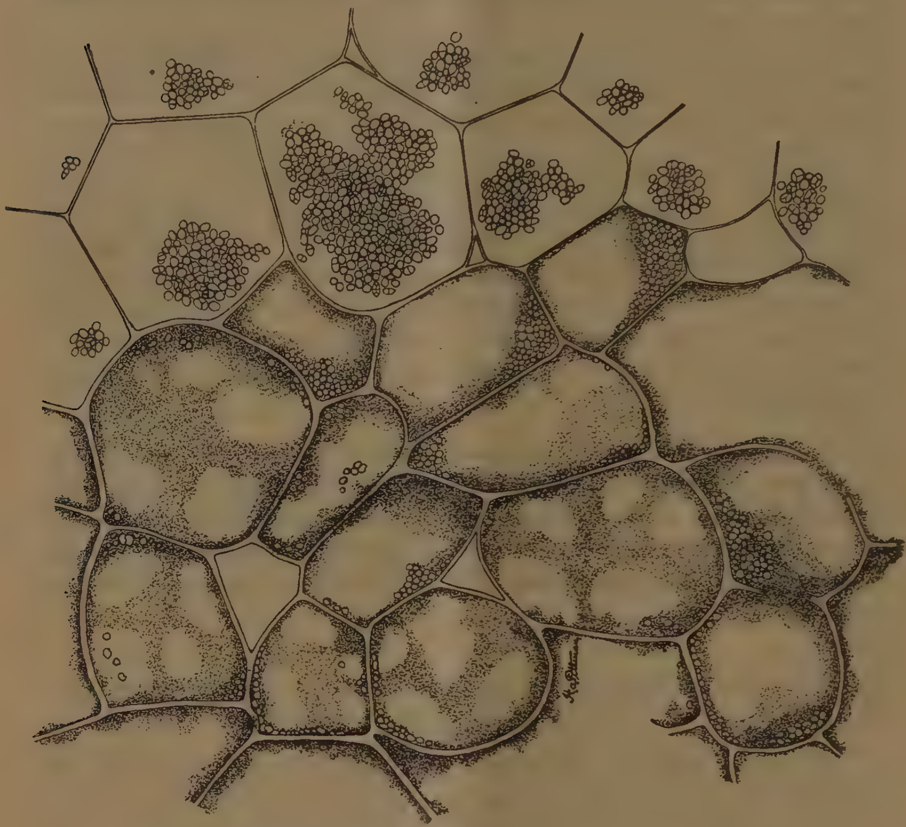
(a) *Pathological Histology of Blotchy Cork Tissue in Cleopatra Apples. Early-season Blotchy Cork.*

In typical cases, the microscopic appearance of early season blotchy cork lesions is quite distinct from that presented by bitter pit.

Cleopatra apples, badly affected with blotchy cork, were obtained in January, 1928, the severity of the lesions, both internally and externally, suggesting that the apples had been affected for some time before they were picked from the trees. Iodine tests indicated that the ripening process from the point of view of starch disappearance had not yet begun, and microscopic examination revealed that the healthy cells were tightly packed with starch grains.

The diseased areas were found to be closely associated with branches of the vascular network, some lying at the extremities of the vascular branches, and others closely alongside them. In many cases those portions of the vascular bundles in close association with the necrotic areas were strongly browned. Numerous breaks and cavities in the diseased tissue were in evidence, many of the cavities having their apices at the extremity of a vascular bundle. Very little cell collapse was present, the tissues in this respect contrasting sharply with the appearance of normal bitter pit lesions.

The cell walls of the parenchymatous "cork" tissue were considerably thicker than those of the neighbouring healthy cells.



SECTION OF BLOTCHY CORK TISSUE FROM CLEOPATRA APPLE.

Camera lucida, x 220.

(Note thickness of cell walls, corrosion and disappearance of starch grains and abundance of amorphous brown material in the affected cells.)

(Fig. 10 and text figure above.) This thickening of the cell walls was a very noticeable feature and a phenomenon which we have never found to occur in bitter pit lesions. (Fig. 11.) Numerous measurements revealed that the average thickness of the walls of the cells comprising the cork tissue was in the vicinity of 4.25 μ, with a range of from 2.1 up to 6.5 μ in individual cases. The walls of the neighbouring healthy cells averaged about 1.8 μ, with a range of from 1.4 up to 3.2 μ.

A very striking feature was the presence of an abundance of brown amorphous material in the cell cavities, which was presumably largely the remains of the cell protoplasm coloured by the oxidation products of tannic acid. This brown material in very many instances was

closely applied to the cell walls giving them a false appearance of still extra thickness. (Text fig. p. 22 and Fig. 10.) Owing to the great irregularity in the thickness of the brown deposit, the cell walls of cork tissue commonly had the appearance of being covered with numerous brown protuberances. The junction between the brown protuberant deposit and the true boundary of the cell walls could, in most cases, readily be made out, and care was taken to avoid including any of the brown deposit in arriving at the measurements of the thickness of the cell walls.

A peculiar feature of the cork tissue was that although the apples were quite immature and the healthy cells still packed with starch grains, the starch grains in the affected cells were, in many cases, conspicuously less in number than in the healthy cells, and many of the remaining ones bore marked evidence of corrosion. (Text fig. p. 22 and Fig. 10.) The majority of the starch grains in the diseased areas also appeared somewhat roughened and opaque, and seemed to be losing their individuality by merging with their fellows into an amorphous brown-coloured mass.*

Measurements indicated that the average size of the starch grains in the healthy tissue was 14.1 μ in their largest dimension; the range being from 4.3 up to 21.7μ. The starch grains in the diseased cells of the same section, and in the same microscopic field, averaged 5.4μ the range being from less than 1 up to 13μ. Many of the cell walls in the diseased tissue were broken, forming large cavities, but as stated above very little cell collapse had taken place, presumably on account of the increased thickness of the cell walls.

The cell walls of the diseased area and also of the immediately surrounding cells stained markedly with ruthenium red, indicating pectic degeneration.

Controlled microchemical tests carefully carried out with phloroglucin and hydrochloric acid, aniline sulphate and sulphuric acid, zinc chloröiodide, Sudan 3 and freshly prepared chlorophyll solutions, failed to give any evidence of lignification or suberization in the cell walls of diseased or surrounding healthy cells, although repeated tests were made on many different occasions.

There is no foundation for the term cork, in a strictly botanical sense, being applied to the disease, owing to the absence of suberization in the walls of the affected tissue.

However as the diseased areas in the flesh undoubtedly appear corky, and as we are unable to suggest a more generally suitable name, we have decided to retain the term cork, while pointing out that there is no evidence of suberization having taken place.

* The starch grains of apple tissue are mostly compound, being composed of from 1 to 6 simple grains.

Mix (49) in describing the form of the cork disease on Fameuse, &c., which we have termed internal cork, states that the healthy cells adjoining the diseased areas, "form a ladder-like arrangement of smaller, more nearly rectangular cells, as though they had been stimulated to rapid division in response to the decreased pressure from the direction of the diseased area." In the case of late stages of the type of cork described as drouth spot, he states that the walls of these ladder-like healthy cells are suberized. We, however, have not seen any evidence of the formation of a zone of healthy, ladder-like smaller cells tending to cut off the lesions of blotchy cork. Owing to our limited experience with drought-spot cork we are unable to give any opinion as to the suberization or otherwise of the walls of the surrounding healthy cells.

Smith (55) in reviewing the problem of bitter pit, obviously misled by the implied suggestion of the name cork, states:—"The cell walls (of bitter-pit tissue) are not lignified or suberized, contrasting in this respect with the condition known as 'cork' which is met with in American apples." He gives no evidence in support of the latter part of this statement.

Late-season Blotchy Cork.

Cleopatra apples affected with blotchy cork were picked from the trees during early March. From an examination of the external and internal lesions, it appeared that the apples had been affected fairly recently. Moreover these apples were picked in the course of the picking experiments from trees which had shown no evidence of cork during the previous month. Microscopic examination revealed that the majority of the starch granules had disappeared from the healthy cells owing to the normal maturation process taking place in the healthy flesh. The cell walls of the diseased areas in some cases were slightly thicker than the walls of the neighbouring healthy cells, but in other cases no difference could be seen. Sometimes the starch grains in the diseased areas showed considerable evidence of corrosion, but quite commonly very little. Considerable brown amorphous material was always present. Numerous cavities appeared in the diseased tissue, and cell collapse was much more frequent than in the case of early-season cork, possibly on account of the unthickened nature of the cell walls. Many of the lesions of later-season cork examined could not, therefore, be microscopically distinguished with certainty from bitter-pit lesions.

Diseased areas in Cleopatra apples affected with blotchy cork gathered and examined during February showed an intermediate condition, macroscopically and microscopically, between the apples affected in January and those affected in March.

It follows, then, that whereas the lesions of early-season blotchy cork on Cleopatras are quite distinct, macroscopically and microscopically, from those of bitter pit, yet as the end of the season approaches, the differences become less and less marked. Thus though bitter pit and early-season blotchy cork are symptomatically two obviously distinct diseases, late-formed cork may, in the Cleopatra variety at least, be macroscopically and microscopically indistinguishable with certainty from bitter pit. The later the cork is formed the less serious are the lesions, and the less the difference between blotchy cork and pit.

The possible reason for this is discussed under the heading, "The Cause of Cork and Bitter Pit" (p. 62), and the probable relation between the two diseases considered.

(b) *Blotchy Cork on Varieties other than Cleopatra.*

The internal and external features of the lesions of apples, other than Cleopatras, affected with blotchy cork are as follow:—

Sturmer (from Victoria).

Large very irregular depressed areas of shallow depth and dark chocolate-brown colour were found in large numbers on the cheeks of the fruit. Frequently, but not necessarily, they were located towards the calyx region but only seldom close to the pedicel. Many of the smaller blotches, which averaged in size 10 mm. by 7 mm., were confluent. The largest depressions measured 27 mm. by 17 mm., blotches of slightly smaller size being quite common. Most of the depressions showed a very irregular but smooth margin and a depth of from 1 to 1.5 mm. On some apples the depressions showed an olive-green colour mottled with patches of the chocolate-brown. These particular examples very strongly resembled the typical blotchy cork of Cleopatras. The olive-green and the chocolate-brown colour of the depressions contrasted very markedly with the yellow-green or yellow colour of the adjoining healthy parts of the surface. The surfaces of the apples were often somewhat rugose. (Fig. 12.)

Internal examination revealed that the necrosis in the flesh was commonly not as abundant as one would have been led to expect from the seriousness of the external lesions. Thus the necrotic areas on the whole did not extend as deeply into the flesh as in the case of affected Cleopatras, nor were they so compact and definitely delimited. (Fig. 14.) The internal lesions on the whole tended to be very spongy, and straggly rather than compact. Many of the vasculars near the surface were quite obviously browned to the naked eye without having any great area of dead cells extending on either side of them. Some of the more compact necrotic areas measured 6 by 3 mm. when the apple was cut transversely. The lesions very commonly

extended to the skin thus forming the chocolate-brown external lesions, while others were separated therefrom by a number of rows of healthy cells. When the apples were cut longitudinally through the axis necrotic tissue approximately 1-2 mm. in width was sometimes met with extending from the calyx end towards the pedicel, just below the skin, in a manner strongly suggesting certain of McAlpine's figures of confluent pit. (Fig. 13.) No dead areas were found deeply situated in the flesh. The necrotic tissue, when separated from the healthy cells, was found to have a very pronounced bitter taste.

Five Crown (from Victoria).

These apples showed two distinct types of lesions. The first type consisted of very irregular, shallow, chocolate-brown depressions on the surface, comparable in every way with the lesions described above on Sturmer. Many of the larger depressions seemed to be formed by the running together of the smaller ones. The largest external lesions met with measured 20 by 10 mm. The smaller ones averaged 6 by 5 mm.

The other type of lesion consisted of small, fairly sharply depressed, regular to irregular, dark-green pits on a yellow healthy background. These pits were, for the most part, approximately 3 x 3 mm. in surface dimensions. They strongly suggested bitter pit but various intergrades occurred between this type and the above. For instance, chocolate-brown flecks occurred in some of the green pits suggesting that the large chocolate-brown irregular depressions may have begun as groups of green pit-like depressions which ran together and became finally brown, due to the necrotic tissue reaching the surface.

Internally, fairly compact necrotic areas were found measuring approximately 7 by 5 mm. when the apple was cut transversely. Where the chocolate areas were met with on the surface, internal examination revealed that the necrosis extended up to and embraced the epidermis. Where the deep-green colour occurred on the surface the necrotic areas were separated from the epidermis by a variable number of rows of healthy cells. The necrotic tissues in many cases showed a brownish hazy region surrounding them.

Newtown Pippin (from Victoria).

The external lesions varied from very irregular, slightly depressed, deep-green areas, measuring approximately 10 by 7 mm., to others much more conspicuous, dark-brown in colour, irregular, and of the same general type as found in the Sturmer, although generally not so large.

Internally these apples showed very marked and very extensive dead areas just below the surface, in the middle regions of the pulp, or in some cases adjacent to the core region. The internal lesions were

surprisingly more marked than was indicated by the surface disfigurement. Some apples showing hardly any surface markings were very badly affected internally.

Esopus Spitzenberg (from Victoria).

These apples were badly affected with Jonathan spot. In addition, several fairly large irregular light to dark-brown depressions, measuring up to 10 by 6 mm., occurred on the surface. Some of the depressions were so darkly coloured as to be almost black. On cutting the apples tranvsersely, large cork areas were found in the flesh, many occurring close to the core. Many of the apples which gave very little evidence of being affected with cork externally showed a surprising number of large dead areas internally. (Fig. 15.) Indeed some which showed very little external marking supplied the writers with the best examples of cork they have yet seen. None showed any marked malformation, and owing to the confusion with Jonathan spot it would have been difficult to predict, from external examination, that the apples were affected with cork. Some were in a condition indicating a transitional stage between internal and blotchy cork.

Granny Smith (from Victoria and Tasmania).

These apples showed very numerous small deep-green pits generally on one side, but in some cases occurring all around. Each pit was surrounded by an indefinitely delimited hazy green zone. Many were located close to the calyx region. So numerous and so closely grouped were the pits on many apples that a decidedly rugose or corrugated appearance was given to the surface. Some of the pits showed small brown flecks and this with the corrugated appearance suggested that the apples were affected with cork. Internally some apples appeared to be affected with cork while in others the lesions seemed to show closer affinity with orchard pitting. It was obvious that in these apples were lesions on the border-line between blotchy cork and orchard pitting.

Jonathan (from Western Australia).

A number of Jonathan apples were picked on 24th February at Donnybrook, showing numerous fairly regular slightly depressed dark-brown blotches located from the equator to the calyx region. Externally and internally, the lesions were very similar to those described above on Cleopatras. Many of the surface lesions were almost circular, and measured approximately 10 mm. in diameter.

French Crab (from Tasmania).

French Crab apples were received from the Tasmanian Department of Agriculture badly affected with blotchy cork. These apples showed many deep-green almost circular depressed blotches ranging up to

1.6 cm. in diameter. A few of these blotches gave a faint indication of brown showing through from inside. The depressions were only shallow and were flat at the bottom rather than concave. The blotched areas were exceedingly firm and hard to the touch. On cutting, the necrotic areas beneath the skin were found to be very compact, exceedingly hard and tough, and somewhat more extensive than indicated by the external lesions. In some apples large firm necrotic areas were found fairly deep in the flesh.

(iv) Drought-spot Cork.

This term has been adopted to indicate "superficial lesion" of Mix's drouth spot (49). Difficulty has been found in correlating the description of drouth spot given by Mix with that given by Brooks and Fisher. Mix's "deep-seated lesion" we have provisionally placed under blotchy cork. Brooks and Fisher (4) also regard this type of disease as a form of cork.

The only case which was found during the present investigation which appeared definitely to be drought-spot cork occurred on a number of Tasma trees at Karragullen (W.A.). (Fig. 16.) Many of the apples were badly affected with water core towards the end of January. In March much of the water core had disappeared from the fruits but many of them had developed what appeared to be drought-spot, associated, in some cases at least, with water core. Others showed large cork areas associated with water core. (Fig. 17.) Mix's description of his "superficial lesion" here adopted for drought-spot cork is as under:—

"An early stage of the disease is manifested by an irregular, light-brown area in the skin. When the fruits affected are large, two or three centimeters in transverse diameter, the surface of the fruit is usually smooth and regular, there is no shrinkage or sinking in, nor any abnormality in the flesh beneath. On large fruits, also, the lesion occurs often on the cheek of the fruit and is not more common toward the calyx end. When the fruits are smaller, and sometimes on larger fruits, the spots show an irregular, wavy pattern, formed by a series of wrinkles or corrugations, the elevations and depressions of which are, however, very small, and it is rare that there is any abnormality in the flesh of the apple. It is as though the browned areas marked the course of the fine network of vascular endings situated just beneath the skin of the fruit. This idea receives confirmation from a study of cross sections through such lesions placed under the microscope. On young fruits, also, the disease occurs normally toward the calyx end of the fruit, often as a broad collar of diseased tissue just below the base of the calyx lobes.

When the spot first appears tiny drops of a clear or yellowish gummy exudate may occur on its surface. Under the microscope this exudate shows as a clear gum. No organism is found associated with it. It is considered to be merely an expression of cell sap from the diseased hypodermal cells.

Most of the fruits affected when young drop from the tree. Some of them (and this is the rule with fruits which have grown large before becoming diseased) persist, and, as they grow, the affected area becomes roughened and cracked. Often deep-seated cracks are formed. This, of course, is not essentially different

from the cracking which occurs whenever a portion of the skin of the fruit is killed through any cause (as, for instance, a severe attack of apple scab) and the fruit makes subsequent growth." (49 p. 481.)

In the last stage referred to above Mix often found an abnormal tissue forming beneath the dead cell layers. The healthy cells immediately beneath had become nearly or quite rectangular in outline and were apparently in the process of isolating the diseased cells from the healthy pulp. The outermost layer or two of this new tissue had suberized cell walls. (Fig. 49, p. 485.)

3. Orchard Pitting (Tree Pit and Late-formed Cork).

Orchard pitting is the pitting which may occur during the late life of the apples on the trees. Symptomatically a homogeneous group, from a causal point of view two distinct troubles are involved, namely late-formed cork and tree pit.

We have had experience with orchard pitting on Cleopatra, Granny Smith, Five Crown (London Pippin), Shockley, and Rymer. Affected apples usually show a number of greenish circular pits which may be so numerous as to give the apple a slightly rugose appearance. The pits are not so sharply depressed as in the case of apples pitting after picking. (Fig. 19.) Quite commonly they appear to be localized on one side of the apple in a fairly compact group. Some of the pits may show a decidedly brown colour, but most commonly they are greyish or olive-green. The pits are fairly regular in outline and usually about 3 mm. in diameter. On cutting it is sometimes found that the dead tissue below the pits, where numerous, tends to coalesce, thus forming fairly extensive necrotic areas suggesting that the apple is affected with cork. For the most part, however, the pits tend to be associated with comparatively small dead areas as in bitter pit developing in store.

It will be remembered that in the description of late-season blotchy cork on Cleopatras it was stated that as the lesions are formed later and later in the season they tend to become less and less distinguishable both macroscopically and microscopically from bitter pit lesions. It is thus obvious that orchard pitting, from a symptomatic point of view, forms a merging ground between blotchy cork and bitter pit. Some apples classified from a symptomatic stand-point as being affected with orchard pitting may really be affected with late-formed cork, while others may be affected with bitter pit formed on the trees (tree pit).

From a statement in Smith's *Review of the Bitter Pit Problem* (55) it would appear that Heinicke (30) held that the bitter pit disease developing in store is a more or less distinct disease from that developing in apples on the trees. We have, however, been unable to obtain

a copy of Heinicke's paper even from the writer himself, and reference to the abstract in the *Experiment Station Record* for January, 1922, p. 47, throws no light on the matter.

4. Storage Pit (Normal Bitter Pit).

(i) The External Features of Apples affected with Storage Pit.

Storage or normal pit is the bitter pit of apples which develops only after the apples are picked from the trees. (It is considered in this connexion that as soon as an apple is picked it is to all intents and purposes being stored.) The disease is actually initiated in the apples by picking them while in a rapidly ripening but still immature condition.

The lesions develop much more rapidly at ordinary temperatures than in cold storage, but it appears that, under certain conditions, cold storage may actually increase the final amount of pit developing in the fruit, by greatly prolonging the period of susceptibility. Moreover, it has been our experience that bitter-pit lesions developing in cold store are generally much more serious externally than those developing at ordinary temperatures, being, for the most part, larger in diameter, deeper, more sharply depressed, and often much more deeply coloured. (Fig. 1 and Fig. 20.)

The most constant and characteristic feature of apples affected with storage pit is the presence on the surface of the fruit of very conspicuous pits or depressions. These depressions may vary in number from one up to many hundreds. Except when very numerous the pits will almost invariably be found confined to the calyx end of the fruit. They may be clustered in a group on one side of the apple towards the calyx end, or more or less evenly distributed around the surface of the fruit in the region lying between the equator and the calyx depression. When very numerous, some of the pits may be located below the equator region and may even be found extending almost to the pedicel depression.

The pits vary in size from about 1 mm. in diameter up to about 6 mm. or rarely even more. They may be so slightly depressed as to be hardly distinguishable as pits, or so deeply concave as to be hemispherical.

All the pits on a single apple may be almost perfectly circular in surface outline while on another, although of the same variety and taken from the same case, they make be very much more irregular and angular but still subcircular, and yet others may be found showing pits of both types. Apples may even be found with no external pitting but abundant evidence of the disease when examined internally.

Sometimes apples are found in which the pitting is only, as it were, "potential," in the sense that the diseased areas in the flesh may be clearly appreciable to the eye, through the skin, before the depressions have actually formed.

The colour of the pits varies very greatly with the variety affected and is by no means uniform among the individual spots of a single apple. Thus Cleopatra apples taken from cold store will frequently show many pits of a dull grey-green, or brown-green colour, while other pits may be found on the same apples of a very striking, rich glossy chocolate-brown, which contrasts markedly with the green or yellow colour of the surrounding healthy tissue.

Close examination reveals that the colour attributed by the eye to the majority of the pits is really a blend of the healthy skin colour with the particular shade of brown borne by the necrotic tissue in the flesh, seen through the semi-transparent healthy cells above. Thus if the skin is green in colour when the pits are observed, they will appear of a grey-green, or brown-green colour; the particular shade of green depending on the greenness of the skin, the brownness of the necrotic tissue below the depression, and its nearness to the surface. If the apple is kept till the skin yellows, the pits will then appear to be brownish-yellow in colour, showing more of the brown or red-brown tinge the closer the necrotic tissue is to the epidermis. If the necrosis extends from the pulp cells right through the hypodermal region and even includes the epidermis, as is often met with in cold stored apples, the colour of the pits will be the rich glossy chocolate-brown before-mentioned. If alteration of the pigment in the epidermis and the four or five rows of colour-bearing hypodermal cells has taken place, the colour of the pits may even approach black.

To summarize, pits on the green, yellow, or red portions of apples will be some blend of brown with green, yellow, or red respectively, except where the necrotic tissue extends through the hypodermal cells and includes the epidermis, in which case the pits may be very dark in colour, approaching black.

Though there is no definite line of demarcation, a distinction can be drawn between the large, deep, strongly coloured pits and the less conspicuous types. The former, distinguished in this paper as "severe" storage pit, is in our experience confined to cold-stored fruit. The less conspicuous "mild" storage pit cannot readily be distinguished from orchard pitting developed in the orchard in maturing apples.

(ii) Internal Features of Apples affected with Storage Pit.

When an apple affected with storage pit is examined internally, dead clearly-defined brownish coloured areas of varying extent will be found in the flesh immediately beneath the surface depressions. Many other areas of similar nature may be found scattered through the healthy pulp without any external indication, being too deeply situated to occasion any sinking-in of the surface tissues. (Figs. 21 and 22.)

The dead brownish areas are more or less cylindrical, globular, or cone-shaped in outline, and are always found, on microscopic examination, to be intimately associated with one or more branches of the vascular network. Varying, in their greatest dimensions, from about 1 mm. up to approximately 6 mm., or rarely more, they extend inwards towards the core-line in a direction approximately at right angles to the surface.

The dead tissue when close to the surface often appears, to the unaided eye, to include both hypodermal and epidermal cells; but microscopic examination reveals that in the great majority of these cases the necrotic tissue does not extend up to and embrace the epidermis, but is separated therefrom by a variable number of rows of healthy hypodermal cells. In apples which have pitted in cold store the necrosis sometimes extends from the pulp cells through the hypodermal region and embraces the epidermis causing units which are very conspicuous, very sharply delimited and depressed, flattened at the bottom rather than curved, and very dark in colour, sometimes approaching black.

The brown areas, which may or may not appear bitter to the taste, are generally speaking somewhat dry, tough, and spongy, their toughness being such that they can often be readily lifted out as a whole, fairly cleanly from the surrounding healthy pulp.

The sponginess results from the collapse of many of the cell walls towards one another, combined with the tearing away of others, so that fairly large and numerous cavities may be formed throughout the tissue, causing it to become very obviously porous.

As the cell walls collapse towards one another they tend to lock the persistent starch grains, which are generally considered to be the most characteristic feature of Stippen or bitter pit tissue, into longish narrow bands. The breaking away of other cell walls during this process may result in the presence of numerous cavities, the boundaries of which are delimited by collapsed elongated starch-filled cells.

A section of such tissue, therefore, when microscopically examined, presents a peculiarly reticulate or honey-combed appearance contrasting sharply with the continuous mosaic-like pattern of the surrounding healthy starch-free cells. (Text fig. p. 35.) If the shrinkage of the affected tissue has not proceeded very far, only a few cells may be collapsed, and the cavities may be few and widely separated. (Figs. 23 and 24.) The latter condition is the less frequently met with.

The healthy cells, in maturing, gradually lose their starch grains, and eventually arrive at a point when starch no longer occurs. The cells of the diseased tissue, however, for the most part retain their starch grains with peculiar persistency. (Text fig. p. 35 and Fig. 24.)

If apples showing lesions of storage pit are removed from cold store and immediately examined, the necrotic tissue will be found to contain starch grains in considerable abundance. If the apples are

Section of Severe Storage Pit on Dunn's. (From Cold Store.) x 63.
(Note persistence of starch grains and collapse of cell walls in the affected area.)

still not fully mature, the adjoining healthy cells will also contain starch, but not in such great amount. In the course of a few weeks at room temperature, the starch will entirely disappear from the healthy cells, but will still be present in the adjoining diseased ones.

Apples of the Dunn's variety, after being taken from cold store badly pitted, were kept by the writers at room temperature for eighteen weeks. At the end of this time the necrotic areas were still found to contain abundance of starch grains, although the apples were long past their prime and were very badly shrivelled. The healthy cells were quite free from starch grains. Representative apples from the same sample, examined previously, had shown that the healthy cells had become entirely free of starch at least sixteen weeks before.

In addition to very often containing large numbers of persistent starch grains, the cells of storage pit tissue contain a variable amount of brownish material which is apparently the remains of the cell protoplasm, coloured by oxidation products of the tannic acid originally present in the cells. The cell walls are often collapsed or broken, but

are not thicker in any way than the cell walls of the surrounding healthy tissue. Many of them are also quite colourless, but others will be found to be more or less deeply browned, wholly or in part, apparently due to slow impregnation with the oxidation products of the tannic acid.

A feature of storage pit tissue which does not appear to have been generally noted is that those portions of the vascular tissues which are associated with the necrotic areas are themselves very often deeply browned. In some cases this discoloration of the vasculars, which appears to be due to the presence of a brown amorphous material in the vessels, extends a considerable distance through the healthy pulp tissue. A similar browning of the vasculars has been observed by us to sometimes follow the disappearance of a water-cored condition in Tasma apples. The browning of the vasculars seems also to be one of the initial symptoms of internal breakdown, but just what significance this has in connexion with the development of the conditions referred to is unknown.

Concerning the nature of the walls in the necrotic parenchymatous tissue McAlpine and others (43, 44) have shown that the cells walls are not lignified or suberized. McAlpine, however, stated that "the gummy or mucilaginous substance which colours them brown is of a pectic character." Farmer (26) found that the walls appear to be undergoing a kind of pectic degeneration, and react in a marked degree to ruthenium red. Carré and Horne (7) stated that the walls of the dead cells in bitter pit tissue stain intensely with ruthenium red and that partial pectic changes are found in the narrow zone of immediately surrounding cells. This has been confirmed during the present investigations.

Our own investigations using phloroglucin and hydrochloric acid, concentrated aniline sulphate and sulphuric acid, Sudan 3, and freshly prepared chlorophyll solutions (59), have definitely confirmed McAlpine's contention that the cell walls of the necrotic parenchymatous tissue are not lignified or suberized. In all our microchemical tests known lignified or suberized materials were stained simultaneously as controls on the efficacy of the various materials used.

Reverting to the statement made above, that storage pit tissue is very commonly characterized by persistence of the starch grains, it would appear to be almost universally accepted that the presence of starch is an invariable feature of bitter pit tissue. So far as we have been able to ascertain Ewart (22) is the only investigator who has maintained that bitter pit areas can be found free from starch grains. He writes that—

"If bitter pit develops late after storage there may be no more starch grains in the dead tissue than in the general pulp. Sound apples were kept in cool storage for four months. Many of them developed large, deep, bitter pits. Occasional starch containing cells were present in the dead tissue, but not perceptibly more than in the healthy pulp tissue."

The present investigations have shown that under certain conditions bitter pit areas do not necessarily contain starch. Perfectly healthy Cleopatra apples, picked in an immature condition on varying dates during late summer of 1928, were stored in the laboratory at room temperature (65 deg.–80 deg. F.) for six weeks. A random sample, comprising 10 per cent. of the apples, was carefully examined externally and internally for any evidence of bitter pit lesions before the remaining apples were stored. All proved to be quite healthy. At the end of the six weeks' period at room temperature, the stored apples were examined and were found in many cases to be badly pitted. Some showed surface pitting, while others showed numerous approximately cylindrical or globular necrotic areas closely associated with the vascular tissues in the pulp of the calyx end of the apple, but some distance in from the surface. Still other apples showed both types of lesion.

Some of the necrotic areas of both types were then carefully examined to determine their histological characteristics. Very greatly to our surprise, the first areas examined proved to be entirely free of starch grains. So surprising was this discovery that a considerable number of these storage pit lesions were immediately carefully examined, with the result that out of 53 examined (some by sectioning and others by squeezing out on a slide), from a total of ten different apples, only three areas were found to contain any trace of starch. Apart from the absence of starch, however, the lesions were quite typical of bitter pit. The cells were closely associated with the vascular network; they contained the brown material which gives the brown appearance to the tissue in bulk; some of the cells were collapsed while some of the walls were impregnated with the brown material, wholly or in part. The brown material in the cell cavities was not so abundant, however, as usual, nor were there so many collapsed cells or breaks in the tissue. Subsequent investigations gave the same results.

In all, out of 123 pitted areas examined on three different occasions from 25 Cleopatra apples stored for six weeks at room temperature, only six areas were found to have any evidence of starch. In these six cases the starch was found only in a few cells located close to the vasculars. The neighbouring healthy cells were in all cases quite free of starch. Whether the starch had completely disappeared before the development of the necrotic areas, or simply continued to disappear through enzymatic action subsequent to the death of the tissues, we are unable to indicate. The apples were quite immature when placed into store and at that time contained abundance of starch, as shown by iodine tests on the random samples examined at the beginning of the experiments.

It is noteworthy that, so far, it is only in apples which have pitted at room temperature that we have found the pitted areas free from starch.

IV. PIT AND CORK LIABILITY.

It would be interesting to know whether a variety liable to pit is necessarily liable to cork. This has not been determined. Owing to the obvious difficulty of accepting their diagnoses as correct, it has not been possible to accept the lists of pit-susceptible and non-susceptible varieties published by McAlpine (43) and Darnell-Smith (17). Of the varieties mentioned by Barker (68) as suffering from pit in Western Australian consignments in England, Cleopatra and Sturmer are very liable to both blotchy cork and pit. Jonathan, in Western Australia, is slightly liable to blotchy cork, and Rome Beauty is somewhat subject to crinkle cork. Granny Smiths with blotchy cork were received from Victoria and Tasmania. Of the other varieties mentioned by Barker, Dunn's and Rokewood are not, in our experience, subject to cork. With Alfriston, Adam's Pearmain, Cox's Orange Pippin, and Scarlet Pearmain we have had no experience. The subject is one worthy of further investigation.

V. BITTER PIT CHIEFLY A DISEASE OF APPLES IN STORAGE.

Much scattered evidence exists that bitter pit is essentially a disease of apples in storage. It is proposed to briefly review some of this evidence.

As early as 1892 Wortmann (64) in his original description of Stippen, recognized that the disease was essentially one originating after the picking of the fruit. According to McAlpine (43), he stated that it "only appears exceptionally while the fruit is on the tree, and then only in very liable varieties shortly before the fruit is picked, and in overgrown specimens."

In 1886, Crawford (16) reported observations to the fact that "the spots appear more plainly after the fruit has been stored for a few weeks."

Cobb (12), 1895, gave no information as to whether bitter pit developed on the fruit either before or after picking, but his woodcut illustrating the disease strongly suggests the severe type of pitting found by the present writers to originate only in store at low temperatures.

Güssow (27) in 1906, in a description of Stippen, stated that "the injury was not detected till after the apples had been stored."

Davis (18) in 1907 stated that bitter pit was very common in the fruit on the trees in Cape Colony. The fact that this writer objects that Massee's photograph (which is really an excellent one of bitter

pit) "does not give a clear impression of the disease," indicates when considered with other statements made in the article, that he was almost certainly referring to cork, and not pit. The interesting statement is made, however, that cold storage experiments with half ripe and nearly ripe apples placed into storage without any indication of markings, "have shown when taken out that the disease has developed to an even greater extent than that developing on the tree."

Diakonoff (20) in 1910 reported from Russia that "apples placed into store quite clean were soon badly affected with Stippen and rendered worthless."

Jean White (61) stated in 1912, "The disease has proved extremely deleterious to our fruit export trade owing to the fact that it apparently developed during the transit of the fruits however carefully they might be selected and packed."

Brooks and Fisher (4) in 1918, in their irrigation experiments on apple spot diseases, found that there was a much greater development of bitter pit in store than on the trees. Some of their results were as follow:—

Variety.	Bitter Pit on the Trees.	Bitter Pit in Store.
Gano, 1914	0 per cent.	7·0 per cent.
Jonathan, 1915	Practically none	25·8 per cent.
Grimes, 1916	4·1 per cent.	40·8 per cent.

It is reported in the fourth edition of Sorauer's *Handbuch der Pflanzenkrankheiten,* 1921, that a circular questionnaire sent to a large number of apple-growers in Germany by the Chief Horticultural Expert elicited the fact that in most varieties pitting develops only in store.

McAlpine (48) in 1921 stated:—

"In dealing with this (bitter pit) investigation from the Australian point of view, there were two chief problems to be solved. First and most urgent, considering the loss sustained, it was necessary if possible to prevent the development of the trouble during shipment overseas. Second, to prevent the development of the disease in the orchard while the fruit was still growing."

Overholser and Fidler (50) in 1923, working at the University of California, found that the development of bitter pit was the limiting factor in the cold storage of certain varieties of apples. In certain experiments as many as 98 per cent. of the fruits pitted in cold store at 32 deg. F., although quite clean when stored.

Smith (55) in 1926 stated that—

"Certain varieties appear to develop very little bitter pit so long as they remain on the tree although in storage they become affected rapidly." . . . . "Storage on the tree is apparently the most successful kind of storage for retarding bitter pit development in these varieties."

In three experiments carried out by Smith (55) with Cox's Orange Pippins, the percentage of pit when gathered was 2 per cent. In storage, the percentages of pit increased to 41, 49, and 60 per cent. respectively. In two experiments with Ribston Pippins, 2 per cent. and 6 per cent. of pit were present at picking. In storage, the percentages of pit increased to 46 and 55 per cent. respectively.

Wickens and Carne (62) in 1927 reported the results of experiments with Cleopatra apples, in which there was a marked development of pit in store compared with the amount present on the trees at the time of picking. The results were as follow:—

Picked.	Case,	Per cent. Pit when Picked.	Final per cent. of Pit after Storing.
Early	1	5·4	27·0
Early	2	7·9	48·6
Early	3	2·0	16·0
Early	4	1·4	19·7
Late	5	1·9	3·2
Late	6	2·5	7·6

During the present investigation, out of 3,978 apples picked, only 0.15 per cent. were pitted on the trees. Of 3,135 apples perfectly healthy when placed into store, 16 per cent. eventually developed bitter pit. In no case did the fruit on the trees develop as high a percentage of pit as the lowest percentage developed in store.

Great loss occurs annually in early apple shipments from Australia to European markets, due to the development *en route* of bitter pit following the picking of the apples in a pit-free condition. It is not possible to give any accurate estimate of the amount of pit developing annually in Australian apples on the trees. As stated elsewhere, however, from field and other observations we are certain that by far the greater part of the so-called bitter pit on the trees is in reality cork, although it is true that a small amount of tree pit does occur.

VI. THE DEVELOPMENT OF BITTER PIT ASSOCIATED WITH EARLY PICKING OF APPLES.

Brooks and Fisher (4), in the course of their irrigation experiments with Jonathan apples, studied the development of bitter pit in samples of fruit picked from their various experimental plots at three different stages of maturity. The picking dates were separated by 14-day intervals:—" At the time of the first picking, the fruit was still rather green; the second coincided approximately with the commercial picking date; at the third picking the fruit was dead ripe." The apples were stored in a cellar at an average temperature of about 47° F.

There was practically no bitter pit on the fruit at the time of picking. An examination was made 40 days after the last picking. The fruit was cut, and all showing browning of the vascular tissue, or surface pitting, were counted as affected by bitter pit. The results were as under:—

Type of Irrigation.	Per cent. of Pick.	Percentage of Bitter Pit.		
		First Pick.	Second Pick.	Third Pick.
		Apples over 2⅝-inch diameter.		
Heavy	92	33	15	4
Medium..	82	32	12	1
Light	67	13	5	0
Medium then heavy ..	93	44	23	2
		Apples 2⅝-inch diameter and under.		
Heavy	8	23	17	22
Medium..	18	6	2	0
Light	33	8	1	0
Medium then heavy ..	7	17	8	0

Smith (55) combined the above results, giving the percentage of pit in all apples with each treatment at each pick.

Type of Irrigation.	First Pick.	Second Pick.	Third Pick.
Heavy	32	15	5
Medium	28	10	1
Light	12	4	0
Medium then heavy ..	42	22	2

Smith pointed out that:—

"The early picked fruit had developed more than twice as much bitter pit as the fruit of the second picking, while the fruit which had ripened on the trees showed an almost negligible percentage of pitted apples. That this result is not to be explained merely by the fact that the first picking had been longer in store, was indicated by the subsequent behaviour of the samples, for during the ensuing three months the further development of bitter pit was small, and it was approximately the same in each case."

Overholser and Fidler (50) working in California came to the following conclusions in regard to bitter pit of apples:—

"Apples mature when harvested developed less bitter pit in cold storage than those immature when picked." The following results were obtained with Gravensteins :—

	Per cent. of Pit.
First picking (July 18-26)	33
Second picking (Aug. 2-8)	19
Third picking (Aug. 15-26)	9

"Furthermore bitter pit occurred more largely on the less mature side, and on the calyx half of each specimen. Large specimens of each variety developed more bitter pit in cold storage than medium or small-sized fruit. . . . One

year's data indicate that the age of the trees did not materially affect the subsequent development of bitter pit in storage, provided the fruit of each lot was equally mature when harvested."

Sir Alfred Ashbolt, when Agent-General for Tasmania, had a report prepared showing the names of steamers, dates of sailing from last loading port, quantities of apples and pears carried, methods of refrigeration, prices obtained, and comments on the fruit in England for the Australian fruit season of 1923. Of the first sixteen shipments sailing from the last port of loading between 16th February and 23rd March, the apples in ten were stated to be more or less affected with bitter pit. No pit was stated to be present in the remaining 26 shipments between 24th March and 24th May. This argues that the earlier picked apples were the most liable to pit.

Adam (1) in Victoria carried out experiments with Annie Elizabeth apples. Two cases were picked on 28th February, and a further two cases from the same trees on 21st March:—"They were free from pit, though at the time of the first picking there were a few pitted apples, and at the time of the second picking quite a large number of pitted apples remaining on the trees." One case of each picking was stored at 32° F. and the other at 35° F. for two months, and then all at 37° for five subsequent months, with the following results:—

Percentage of Pit in Annie Elizabeth Apples.

Picked—	28/3/23.		21/4/23.	
	32° F.	35° F.	32° F.	35° F.
After two months	30	22	8	6
After five more months at 37° F...	37	21	15	14

Adam concluded that "fruit picked early apparently develops more bitter pit in store than does fruit picked late."

Smith (55) pointed out that Adam's experiments were "robbed of much of their significance by the fact that there was considerable development of bitter pit on the trees in the interval between the pickings. It is possible, therefore, that the pit-liable apples had already been eliminated from the second sample before it was stored."

It is more probable, in our opinion, that the "pit on the trees" was, in reality, cork or tree pit as distinct from storage pit. Taken in conjunction with other data given in this paper, Adam's conclusion would appear to be justified.

Smith (55) carried out experiments in Tasmania on "The Effect of Maturity at Picking on the Subsequent Development of Bitter Pit." The varieties Ribston Pippin and Cox's Orange Pippin were used:—

"The fruit was picked at two stages of maturity, the first date being rather earlier than the commercial picking time for export overseas, while the second represented an exceptionally late picking time, although the fruit was even then not dead ripe."

Percentage of Bitter Pit Developed in Storage at 55-65°F.

i. Ribston Pippin, Bagdad, Tasmania.

	Picked 18/2/25.	Picked 8/3/25.
Examined February 21 ...	2 ...	—
,, March 10 ...	20 ...	4
,, March 26 ...	54 ...	5
,, July 30 ...	46 ...	24

ii. Ribston Pippin, Franklin, Tasmania.

	Picked 18/2/25.	Picked 15/3/25.
Examined February 19 ...	6 ...	—
,, March 16 ...	55 ...	8

iii. Cox's Orange Pippin, Huonville, Tasmania.

	Picked 26/2/25.	Picked 26/3/25.
Examined February 28 ...	2 ...	—
,, March 26 ...	38 ...	15
,, April 25 ...	60 ...	6
,, July 30 ...	60 ...	9

"In all three cases the percentage of bitter pit in fruit of the second picking at the time of gathering was much less than that present on the same date in the stored fruit of the first picking. Thus the rate of bitter pit development was much slower on the tree than off, although the temperatures were approximately the same for both samples. As a matter of fact, even less bitter pit appeared in the fruit left on the tree than in the fruit of the first picking, which was placed in cold storage. Storage on the tree is apparently the most successful kind of storage for retarding bitter pit development in these varieties. Not only had the fruit of the second picking less bitter pit at the time of gathering, but it also developed less bitter pit subsequently in storage. Even after five months, by which time bitter pit had probably become evident in all the apples in which it would ever appear, the fruit of the second picking still showed a much smaller percentage than that of the first picking. This was particularly so in Cox's Orange Pippins, the second picking of which developed surprisingly little bitter pit, besides being superior to the first picking in appearance and taste."

Smith, in summing up, states:—

"In certain varieties bitter pit characteristically makes its appearance while the fruit is on the tree, but in others it seems to be inhibited while the fruit is on the tree, although it may develop rapidly after picking. In the latter case it has been found to develop in storage to a much greater extent in fruit which has been gathered in a relatively immature condition, than in fruit allowed to ripen on the tree."

If, therefore, it be accepted, as suggested in this paper, that the so-called "pit" developed on the fruit while on the tree is really cork or tree pit, as distinct from storage pit, Smith's conclusions definitely support the contention that the development of the latter is directly related to the maturity of the fruit when picked.

Wickens and Carne, in Western Australia, carried out experiments to test Smith's conclusions—

(*a*) that the development of pit in stored apples of some varieties is definitely related to their maturity when picked;

(*b*) that cold storage reduces the rate of pit development; and

(*c*) tentatively put forward by Smith that bitter pit may originate in store.

The variety Cleopatra was used, and three pickings were made, one half of each picking being placed in cold store, and the other in ordinary storage. The results were as follow:—

Percentage of Pit Developed in Cleopatra Apples.

Examined.	Picked 23/2/27.		Picked 10/3/27.	
	Cold Store. 289 apples.	Open Store. 288 apples.	Cold Store. 258 apples.	Open Store. 157 apples.
22/2/27	3·6	4·5	—	—
10–11/3/27	6·04	24·6	1·9	2·5
14/6/27	21·47	33·68	3·2	7·6
Increase in store	17·87	29·18	1·3	5·1

It is very probable, in the light of our present knowledge, that the pit given as affecting the fruit when picked was in reality blotchy cork, a trouble to which Cleopatra fruits on the tree are extremely liable.

Wickens and Carne concluded that pit does originate in Cleopatra apples in store, and to an extent determined by their immaturity at picking time. They also concluded that Western Australian Cleopatras should not be picked before the first week of March in a normal season, and preferably not until the second week.

Barker, in his report on the "Cause and Prevention of Wastage in Australian Fruit imported into England" (see p. 82), for the British Department of Scientific Research, states:—"It has long been known that bitter pit is much more extensive in early than in late shipments."

The following market report was received from Ph. Astheimer and Son, Hamburg, dated 14th April, 1928, concerning the condition of Western Australian apples, ex s.s. *Tekoa,* shipped from Fremantle on 18th February, 1928:

"We are very sorry to report that this first cargo of West Australian fruit has been a very great disappointment to the trade. When the steamer arrived here about two weeks ago, most of the fruit was so green and colourless that it could not be offered, inasmuch as the trade was not prepared to take this cargo in such a condition. Only a few of the most advanced lots could be disposed of.

In the meantime the fruit had taken on some more colour. The Dunn Seedlings now showed themselves in a fair condition. The Cleos, however, were in most instances covered with very much bitter pit, and with the colour not too good it was very difficult to interest the trade in such fruit.

The Jonathans were no longer as green as at the time of arrival, but were now partly of a yellowish colour. In a great many instances, however, the Jonathans were not clear, but of rather a dull appearance and rusty.

Altogether it is evident that the fruit shipped ex s.s. *Tekoa* was picked entirely too early, and it would have been far better if the fruit had been left on the trees for at least two weeks more.

We also feel quite certain that bitter pit would not have been so much in evidence, if the fruit had been picked riper, as experience has taught that this disease is always noticeable on large, early picked fruit. . . . .

The shippers of West Australian apples should therefore understand that it is absolutely useless to pick and ship their fruit so early, and to land it here in poor condition, while apples from other countries are at the same time in the market, and command the interests of the buyers."

The same firm in their market report dated 4th May, referring to fruit shipped from Western Australia by the *Port Huon,* which left Fremantle on 20th March, stated:—

West Australian Apples.—Compared with the first cargo ex *Tekoa*, this shipment was certainly a great improvement. . . . *Cleopatra Apples.*—While some lots showed some bitter pit, it was not so pronounced as in the first cargo. The colour had greatly improved and was in most instances satisfactory.

In their report dated 11th May, referring to Cleopatra apples shipped from Western Australia on 25th March by the *Port Brisbane,* occurs the statement:—"Bitter pit was not so much in evidence."

It is obvious from the foregoing references that definite evidence exists in regard to three points:—

(i) That pit does originate in stored apples.

(ii) That the more immature the apples are at picking time, the greater their liability to develop pit in storage.

(iii) That bitter pit is more liable to develop in early than later shipments of apples of the same varieties. This is a natural corollary of (ii).

VII. PICKING AND STORAGE EXPERIMENTS WITH CLEOPATRA APPLES, 1928.

The variety Cleopatra was selected because of its reputation for extreme liability to bitter pit. As shown elsewhere this reputation proved to be quite justified, though earned to a large extent by its decided liability to cork while on the trees.

It was evident in January that the apple crop would be a small one, and it was feared that bitter pit would be unusually prevalent. This fear was based upon the generally accepted idea that small crops and consequent large fruits are very liable to bitter pit. We know now that this idea had reference to cork. Nevertheless in our experience and that of the Superintendent of Horticulture, less cork

occurred in Western Australia this season than normally. As an indication of the smallness of the crop, the number of cases exported this year, for the period 1st January to 5th May, was 152,000 as against 464,000 in 1927.

To avoid complications which might arise from the unusual conditions of this season, it was decided to look for trees carrying normal crops. These were found in the Illawarra company's orchard at Karragullen. Rights over the crop of seven trees were secured early in January, and arrangements were made that fruit would not be interfered with, or windfalls removed. The trees were about 30 years old, of approximately the same size, and grouped together, four in one row and three in that adjoining. One tree was reserved for observation purposes, and the remaining six were used for the picking tests. On the 4th January, the crop on the six trees was estimated at 40 cases, but eventually proved to be over 50 cases.

The Illawarra orchard, though not in one of the main apple-growing centres, is one of the best managed in the State. It is situated in an open valley in the Darling Ranges, at an elevation of about 800 feet, 19½ miles south-east from Perth, and about 27 miles by road *via* Kelmscott. The annual rainfall averages approximately 43 inches, of which about 35 inches fall from April to September.

Picking for the experiment commenced on 6th February, and was repeated weekly until 12th March. Five to six cases were picked on each occasion, and taken by motor car to Perth. On the next day the fruit was carefully examined and measured, all bruised fruit removed, and all showing disease set aside for detailed examination. Together with clean fruit, approximately 20 per cent. of the pickings were used for laboratory investigations. The remaining clean fruits were then graded into sizes as follows:—Under 6.3 cm. (under 2½ inches), 6.3 to 7.0 cm. (2½ to 2¾ inches), 7.1 to 7.5 cm. (2¾ to 3 inches), and 7.6 cm. and over (over 3 inches) measured across the greatest width. For convenience apples under 6.3 cm. are noted as size A, 6.3 to 7.0 cm. as size B, 7.1 to 7.5 cm. as size C, and over 7.5 cm. as size D. This has no reference to quality grades, and is used to simplify tabulation only. They were then packed without wrapping, except when otherwise stated, and placed into store. Portion of the fruit was cold-stored in the Western Ice Company's cold store in Perth, and the balance kept at room temperature in the laboratory. For several weeks the fruit in store was examined weekly, but it having been found that storage pit cannot always be recognized with certainty without cutting the fruit, this was discontinued.

At the end of six weeks the fruit stored in the laboratory was cut up and examined. It was found that this period represented sufficiently closely the commercial life of the apple in open store. In the

earlier pickings in particular shrivelling was then marked. The cold-stored fruits were kept in store for ten weeks, and were then removed to the laboratory where they were kept two weeks before final examination. This was done to reproduce as far as possible the conditions to which exported apples are subjected.

In all cases, the figures given for pit are those obtained when the apples were cut up. It was found that apples may have storage pit with little or no external evidence. In other cases, apples with one or two lesions suspected of being affected with storage pit, when cut were found to be only bruised, probably by contact with the stems of other apples. All doubtful cases of pitting, and fruits on which only a single lesion occurred, were excluded. Any errors of identification which may have occurred would cause the figures given to be less than the amount of storage pit actually present.

First Picking.

Six hundred and seventy-nine apples were picked on 6th February, of which 4.2 per cent. had blotchy cork, and 63.6 per cent. of the clean were of size B or larger.

The fruit in the laboratory was finally examined on the 19th March. At this time it was well coloured, but shrivelling had set in, and the fruit was on the point of becoming of no commercial value. The flavour was crude and inferior, and no starch could be detected microscopically after treatment with iodine. The fruit in cold store was removed to the laboratory on the 16th April, and finally examined on the 30th April. It was then in sound condition, but green, and of poor flavour. Starch was present when the fruit was removed from cold store, but had practically disappeared two weeks later. The results are given below:—

Date Stored.	Number of Apples.	Size.	Storage.	Time.	Severe Pit.	Mild Pit.
					%	%
6.2.28 ..	105	A	Laboratory	6 weeks	..	9·5
	85	B	”	”	..	23·5
7.2.28 ..	105	A	Cold, 33° F. to 36° F.	10 weeks + 2 weeks laboratory	18·1	15·2
	183	B			6·5	23·5
	88	B*			13·6	21·6

* Indicates fruit wrapped in sulphite paper.

Second Picking.

Seven hundred and sixty-two apples were picked on 13th February, of which 5.1 per cent. had blotchy cork, and of the clean 50.7 per cent. were size A, 38.5 per cent. B, and 10.8 per cent. C and D. There were 59 windfalls, of which 6.8 per cent. had blotchy cork.

The fruit in the laboratory was finally examined on 26th March. It was well-coloured, in fair condition, but of poor flavour. The cold-stored fruit was removed to the laboratory on 24th April, and finally examined on 8th May:—

Date Stored.	Number of Apples.	Size.	Storage.	Time.	Severe Pit.	Mild Pit.
					%	%
13.2.28 ..	156	A	Laboratory	6 weeks	..	17·3
	53	B	"	"	..	26·4
	35	C or D	"	"	..	20·0
14.2.28 ..	156	A	Cold, 33° F. to 35° F.	10 weeks + 2 weeks laboratory	14·8	6·5
	50	B			22·0	6·0
	96	B*			15·6	9·4
	35	C or D			28·6	22·8

* Indicates fruit wrapped in sulphite paper.

Third Picking.

Six hundred and sixty-six apples were picked on the 20th February, of which 6 per cent. were affected with blotchy cork. Size groups were 34.4 per cent. A, 49.5 per cent. B, and 16.1 per cent. C or D. Seventy-four windfalls had 5.4 per cent. blotchy cork.

The fruit in the laboratory was finally examined on the 2nd April. That in cold store was removed to the laboratory on the 1st May, and finally examined on 14th May. In both cases, the fruit was in good condition, but of poor flavour. Storage pit, though present, was not sufficient to be of any economic importance in the room-stored fruit. The larger and darker-coloured lesions in the cold-stored fruit were sufficient to affect the selling value:—

Date Stored.	Number of Apples.	Size.	Storage.	Time.	Severe Pit.	Mild Pit.
					%	%
20.2.28 ..	40	A	Laboratory	6 weeks	..	17·5
	103	B	"	"	..	8·7
	44	C or D	"	"	..	15·9
21.2.28 ..	156	A	Cold, 33° F. to 36° F.	10 weeks + 2 weeks laboratory	10·7	7·3
	51	B			5·9	1·9
	99	B*			11·2	3·9
	40	C or D			25·0	12·5

* Indicates fruit wrapped in sulphite paper.

Fourth Picking.

Six hundred and fifty apples were picked on 27th February, of which 6.8 per cent. had blotchy cork, and 0.8 per cent. orchard pitting; 147 windfalls had 3.4 per cent. blotchy cork. The size groups of picked fruit were 33.9 per cent. A, with 5.4 per cent. cork, 46.9 per cent. B, with 8.3 per cent. cork, and 19.2 per cent. C. or D., with 4.8 per cent. cork.

The fruit when picked was well developed, though showing little evidence of maturity. When finally examined it was in good condition, with fair flavour. That in open store was well-coloured, and storage pit, though present, was of little or no commercial importance, the surface lesions being few or small, with a correspondingly slight development of internal browning. In the cold stored fruit the lesions were much larger, and were sufficient to indicate obviously that the fruit was affected:—

Date Stored.	Number of Apples.	Size.	Storage.	Time.	Severe Pit.	Mild Pit.
					%	%
27.2.28 ..	80	A	Laboratory	6 weeks	..	12·5
	99	B	"	"	..	13·1
	38	C or D	"	"	..	23·7
28.2.28 ..	83	A	Cold	10 weeks + 2 weeks laboratory	9·6	7·3
	100	B	"		8·0	4.0
	41	C or D	"		14·6	12.2

Fifth Picking.

Six hundred and thirty-four apples were picked on 5th March, of which 1.42 per cent. had blotchy cork, and 0.2 per cent. orchard pitting; 248 windfalls showed 1.2 per cent. blotchy cork. Picked fruit size groups were 43.0 per cent. A, 44.1 per cent. B, and 12.9 per cent. C or D. The starch reactions for this picking are shown in Figs. 28 and 29.

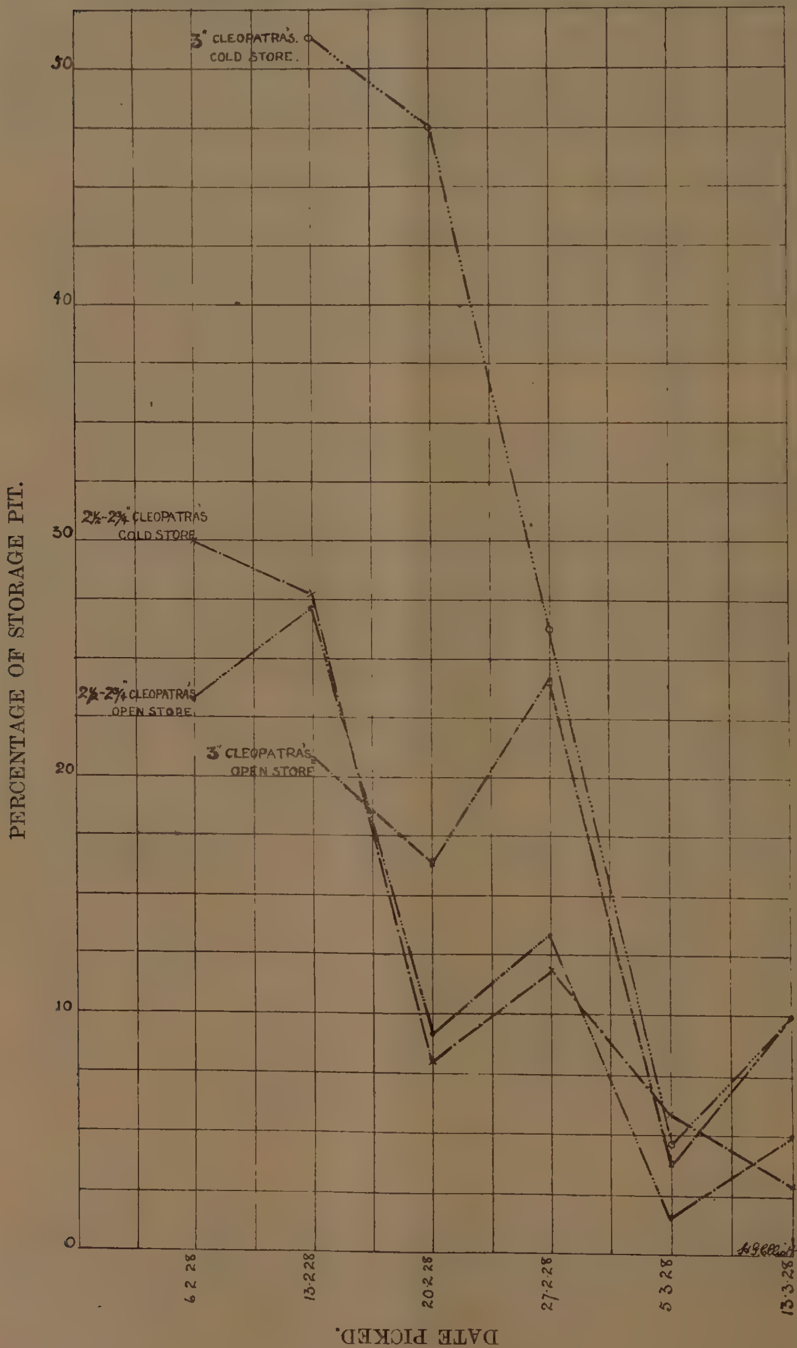
The fruit when picked, in general, showed a faint yellowing of the green colour. When finally examined the condition was very good, and the flavour excellent. This was undoubtedly the best picking in the experiment. The amount of storage pit in both open and cold store was negligible, though that in the cold store was more evident:—

Date Stored.	Number of Apples.	Size.	Storage.	Time.	Severe Pit.	Mild Pit.
					%	%
5.3.28 ..	89	A	Laboratory	6 weeks	..	4·5
	116	B	"	"	..	1·7
	25	C or D	"	"	..	4·0
6.3.28 ..	159	A	Cold	10 weeks + 2 weeks laboratory	3·7	2·6
	100	B	"		4·0	2·0
	41	C or D	"		4·9	..

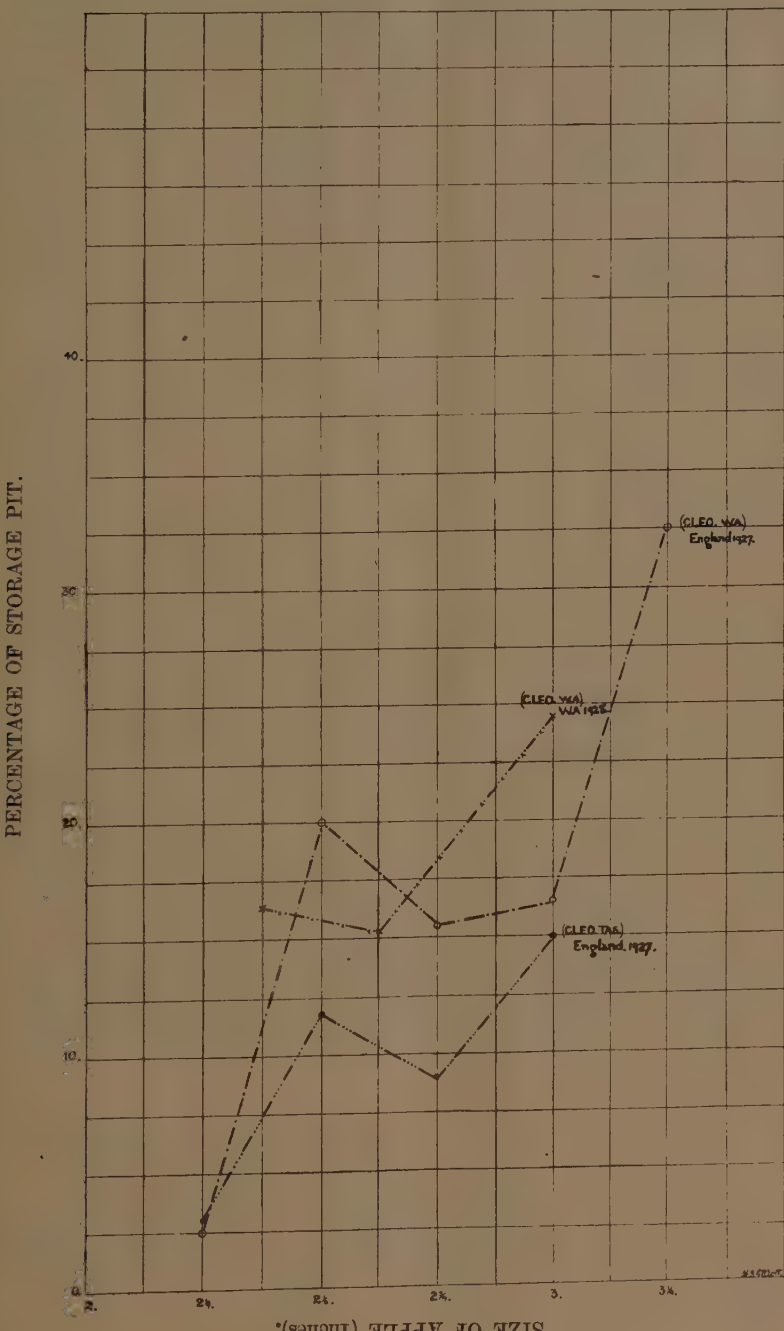
Sixth Picking.

Five hundred and eighty-seven apples were picked on 12th March, of which 4.26 per cent. were affected with blotchy cork, and 474 windfalls with 4.0 per cent. blotchy cork. Size groupings of picked apples were as follows:—15 per cent. A with 5.7 per cent. cork, 44.7 per cent. B with 4.5 per cent. cork, 26.6 per cent. C with 4.5 per cent. cork, and 13.7 per cent. D with 1.3 per cent cork.

RELATIONSHIP OF STORAGE PIT TO MATURITY AT PICKING.



RELATIONSHIP OF STORAGE PIT TO SIZE OF APPLES.



When picked, much of the fruit showed definite indications of approaching maturity, though some was still quite green. When finally examined (open store 23rd April, 1928; cold store 5th June, 1928), the fruit was in very good condition, though not equal in flavour to the previous picking, except in some fruits. Storage pit, though present on more fruits than in the previous picking, was only in small quantity in the affected fruits. The amount developed on each affected fruit, even in cold store, was almost negligible. A faint pinkish discolouration around the core in some of the fruits 7.6 cm. in diameter or over, developed in cold store, indicating the first signs of internal breakdown.

Date Stored.	Number of Apples.	Size.	Storage.	Time.	Severe Pit.	Mild Pit.
					%	%
12.3.28 ..	100	B	Laboratory	6 weeks	..	5·0
	40	C or D	,,	,,	..	10·0
13.2.28 ..	75	A	Cold	10 weeks + 2 weeks laboratory	..	5·3
	112	B	,,		..	2·7
	80	C	,,		1·2	8·8
	64	D	,,		3·1	3·1

Reference to Table 4 shows that there is a general fall in the amount of bitter pit developed in commercial sizes following later and later picking dates, and indicates that, the riper the fruit the smaller the amount of bitter pit developed during storage. The apparent departures from this regular fall in relation to picking date may be explained by reference to the starch reactions of each picking. It was noted that each rise in the amount of storage pit was related to a decreased ripeness, as shown by the iodine reactions, in the fruit when stored. When picking the fruit it was the practice to pick from three trees one week and the other three the succeeding week. No attempt was made to pick the fruit according to ripeness, the object being to obtain each time fruit of all sizes and stages of ripeness. The outcome of this procedure was that in several cases some at least of the fruit picked one week was less matured than the least matured of the previous week.

In the text figure p. 48 these results are shown in graphic form. In the text figure p. 49 the percentages of storage pit developed in apples of different sizes in these experiments are compared with those reported for Cleopatra apples from Western Australia and Tasmania in England as given in Special Report No. 3, 1928, of the Empire Marketing Board.

Three tests were made in cold store of apples 6.3-7.0 cm. in diameter wrapped in ordinary sulphite wrappers. The results appear to indicate a tendency for wrapping to increase pit, but are inconclusive.

TABLE 4.—EFFECT OF MATURITY AT PICKING ON THE SUBSEQUENT DEVELOPMENT OF STORAGE PIT.

Size.	Date Picked.	Open Store. Date Cut.	Open Store. Number Apples.	Open Store. Percentage Pit.	Cold Store. Date Cut.	Cold Store. Number Apples.	Cold Store. Percentage Pit.	Cold Store (Wrapped). Date Cut.	Cold Store (Wrapped). Number Apples.	Cold Store (Wrapped). Percentage Pit.
				%			%			%
Under 6·3 cms. (or 2½ inches) ..	6.2.28	19.3.28	105	9·5	30.4.28	105	33·3	..	..	..
	13.2.28	26.3.28	156	17·3	8.5.28	169	21·3	..	..	..
	20.2.28	2.4.28	40	17·5	14.5.28	156	18·0	..	..	..
	27.2.28	11.4.28	80	12·5	21.5.28	83	16·9	..	..	..
	5.3.28	17.4.28	89	4·5	28.5.28	159	6·3	..	..	..
	12.3.28	23.4.28	..	..	5.6.28	75	5·3	..	..	..
Mean	..	..	..	12·3	..	..	16·9	..	..	..
6·3–7·0 cms. (2½–2¾ inches) ..	6.2.28	19.3.28	85	23·5	30.4.28	183	30·0	30.4.28	88	35·2
	13.2.28	26.3.28	53	26·4	8.5.28	50	28·0	8.5.28	96	25·0
	20.2.28	2.4.28	103	8·7	14.5.28	51	7·8	14.5.28	99	15·1
	27.2.28	11.4.28	99	13·1	21.5.28	100	12·0	..	..	..
	5.3.28	17.4.28	116	1·7	28.5.28	100	6·0	..	..	..
	12.3.28	23.4.28	100	5·0	5.6.28	112	2·7	..	..	..
Mean	..	..	..	11·3	..	..	15·7	..	..	24·7
Over 7·0 cms. (2¾ inches and over)	6.2.28	..	..	..	..	..	..	..	..	..
	13.2.28	26.3.28	35	20·0	8.5.28	35	51·4	..	..	..
	20.2.28	2.4.28	44	15·9	14.5.28	40	47·5	..	..	..
	27.2.28	11.4.28	38	23·7	21.5.28	41	26·8	..	..	..
	5.3.28	17.4.28	25	4·0	28.5.28	41	4·9	..	..	..
	12.3.28	23.4.28	40	10·0	5.6.28	80	10·0	..	..	..
Mean	..	..	..	15·4	..	..	24·5	..	..	..
Over 7·6 cms. (3 inches and over)	12.3.28	..	..	..	5.6.28	64	6·2	..	..	..
Mean	..	..	..	..	..	..	6·2	..	..	..
Total	..	..	1,208	12·3 (mean)	..	1,644	17·2 (mean)	..	283	24·7 (mean)

All Sizes—3,135 Apples; 502 pitted = 16 per cent.

The conclusions to be arrived at from this experiment are:—

(i) That the amount of bitter pit developed in apples in storage decreases the closer they are to maturity when picked.

(ii) That cold storage of immature apples tends to increase the amount and severity of bitter pit as compared with storage at room temperature (60 deg.–80 deg. F.).

(iii) That large fruit is more liable to bitter pit than small fruit.

(iv) That for the trees used in experiment the best period for picking in 1928 occurred during the first week of March.

That bitter pit is related to maturity at picking time is beyond doubt, as the results of this experiment and of experiments quoted elsewhere (p. 40) in this paper show, and the fact is already accepted in commercial circles.

That cold storage increases the amount and severity of bitter pit in immature apples is shown by this experiment and by those carried out here in 1925 (see Smith 55). Similar results were obtained with a case of Granny Smith apples. These were obtained from Karragullen on 5th March. There were 127 fruits, of which one (0.8 per cent.) had blotchy cork. 120 were stored as under:—

63 apples, in laboratory 5th March, 1928; examined 23rd April, 1928; storage pit 1.6 per cent.

57 apples, in cold store 6th March, 1928; examined 28th May, 1928; storage pit 8.8 per cent.

The view that large fruits are more subject than smaller is readily accepted elsewhere (43, 68), and has been found the case in Australian fruit in England (66).

The finding that the best date of picking this season, from trees selected as bearing normal crops, was the first week in March, is strikingly confirmative of the prediction made in 1927 by Wickens and Carne (62).

VIII. THE MATURITY OF APPLES.

1. General Considerations.

The evidence put forward elsewhere in this work leaves no doubt that the development of bitter pit in apples and their degree of maturity when picked are definitely associated. It therefore becomes highly desirable to find some means by which the degree of maturity of apples can be definitely determined.

Bigelow, Gore, and Howard (3) have defined maturity, in a chemical sense, as that stage in the development of an apple when it ceases to contain starch. Carne (5) adopted the same definition to apply to maturity in a general sense, but pointed out that mature apples were not necessarily ripe apples. Because of the fact that immature apples, when picked, rapidly lose their starch (as shown by Bigelow, Gore, and Howard and confirmed by the writers) without gaining either the flavour or texture of ripe apples, it is evident that they cannot then truly be said to be mature, either in a popular or in a chemical sense.

We have therefore adopted the following definitions for maturity, one to indicate the stage at which apples may be safely picked for storage, and the other to indicate the stage at which the maturation processes are complete.

(i) *Picking Maturity* is the stage in the development of an apple after which, if picked, it will continue its normal ripening processes, i.e., pass to full maturity.

(ii) *Full Maturity or Ripeness* is that stage in the life of an apple when the ripening processes are completed, i.e., when the apple has developed its characteristic flavour and texture and contains very little or no starch.

The differences between apples of the same variety which have reached full maturity in store, and those which have ripened on the trees are slight. Apples stored for sufficient length of time become finally devoid of starch, while those ripened on the tree may contain a small amount (Bigelow, Gore, and Howard). Apples stored usually develop less colour than tree-ripened apples, but colour cannot be entirely relied upon as an evidence of maturity, varying as it does with the locality, soil, and position of the fruit on the trees.

Immaturity, in the sense used in this paper, refers to all stages of development up to picking maturity. Immature apples, if stored, rapidly lose their starch; are devoid of the characteristic flavour and texture of mature apples; soon shrivel; do not colour properly; and do not develop the greasiness characteristic of many varieties, such as Dunn's and Cleopatra, when stored at a proper stage of maturity.

It has been recognized for some years that much immature fruit has been exported from Australia to the detriment of the reputation of Australian apples in Europe, and the Department of Markets of the Commonwealth Government decided to take action. Under Customs Proclamation of 29th April, 1920, the exportation of fruit so immature that it was likely to shrivel or wilt had been prohibited. It was therefore decided by the authorities that no fruit should be exported in 1928 before 1st March.

"If, however, the fruit is sufficiently matured to warrant exportation, i.e., has reached that stage of maturity when, after picking, it will complete its ripening process and, in the opinion of the inspectors, is likely to arrive at its destination in a sound condition,"

permission for exportation during February might be granted. This practically meant that the responsibility for determining whether the fruit had reached the picking maturity stage when picked was thrown on the Commonwealth inspectors. That the inspectors failed is evident from the report (given elsewhere in this paper) on the *Tekoa* shipment which left Fremantle on 18th February, 1928. It is also clear that merely fixing the date of export is not a reliable method of ensuring that fruit shall be picked sufficiently mature. There is nothing to prevent the fruit being picked weeks before and being cold stored pending shipment, as happened in the case of much of the *Tekoa* and *Tritonia* consignments. No method of control of maturity can be satisfactory unless it operates directly on the date of picking.

Two methods of determining maturity were tested—(i) Starch iodine reaction; (ii) Mechanical pressure tester.

Starch-Iodine Reaction.

This test is based upon the known disappearance of starch in maturing apples, and the absence, or practical absence of starch in fully-matured apples. If an apple is picked straight from the tree, cut, and the cut surfaces treated with an iodine and potassium iodine solution,* the cut surface is rapidly stained violet-blue or blackish to an extent proportional to the amount of starch in the cells at, or close to, the cut surface. These cut surfaces photograph well, especially if treated with sulphur dioxide to prevent the normal browning of the tissues by oxidation processes. This system of indicating the maturity of apples was apparently first used by Bigelow, Gore, and Howard (3) in 1905.

The following account is based mainly on our investigations on the Cleopatra apple. Tests made with other varieties indicate that while differences of detail occur, in general the process of ripening is the same for all apples. If apples are examined shortly after picking, it will be found by staining them for starch in longitudinal section, and in transverse sections made through the calyx, equatorial and stem portions, that the loss of starch commences at two points. A longitudinal section through the axis reveals that in the main flesh of the apple outside the core line, starch disappearance commences round about the point of insertion of the pedicel or stalk. At the same time, starch commences to disappear within the core line. If

* Iodine Solution for Starch Detection.—Dissolve 1 gm. potassium iodide and 0.25 gm. iodine, in 100 cc. water, by gently heating if necessary.

transverse sections through the calyx, equatorial and stem ends are stained, it will be found that the equatorial section shows a mean stage of ripeness (as indicated by starch disappearance) for the whole apple (See Fig. 27). The reason for this is shown by staining longitudinal sections (Fig. 28), in which it will be seen that starch loss proceeds in a general way in the flesh of the apple from stem end to calyx end. An apple still not fully matured therefore tends to be most mature at the stem end, and least mature at the calyx end.

When a series of apples is picked from trees with fruit at different stages of ripeness and stained for starch in equatorial section, they will be found to pass through the following stages:—When quite immature, the cut surface is all stained violet-blue to almost black; when somewhat more mature patches of tissue within the core line do not show the starch reaction; and still more developed apples show the starch disappearance to be extending within the core line, and in more or less regular, scattered patches through the rest of the flesh.

At first the starch outside the core line tends to disappear in triangular areas extending outwards, and separated by other triangular areas of starch-filled cells having their apices on the main vasculars of the core line. This regularity soon disappears, and the starch-filled triangular areas form V's. The starch is retained longest around the vasculars, appearing in the later stages of ripening, when stained, as dark spots scattered through the flesh, but principally close to, or just beneath, the surface. The process of starch disappearance as met with in our experience, conforms, in a general way, to that described by Bigelow, Gore, and Howard (3), though in Cleopatras there is very much less regularity than in the varieties they described. Granny Smiths tested by us showed greater regularity than Cleopatras (Fig. 29), and Yates ripened very much more evenly than either (Fig. 30). Moreover, whereas Cleopatra, Granny Smith, and varieties described by Bigelow, Gore, and Howard, appear to ripen, in a general sense, outwards from the core region towards the periphery, Yates appears to ripen in the peripheral region to a depth of about 10-15 mm. fom the skin, slightly in advance of the remainder of the flesh. Thus it comes about that the peripheral zone is free from starch in that variety, while there may still be a small amount in the core region and scattered elsewhere through the pulp.

We may sum up the process of starch disappearance in the flesh of Cleopatra apples thus:—The starch commences to disappear in those cells which are so situated as to be as remote as possible from the various neighbouring vascular bundles. From these zones the maturation process (from a starch disappearance point of view) works gradually outwards towards the vasculars. It is therefore

obvious that the cells which are the last to lose their starch must be those which are located either alongside or at the extremities of the vascular bundles.

As the calyx region of the apple is the last region to complete the maturation process, it follows that the cells either alongside or at the extremities of the vascular bundles in the calyx region, will be the last cells in the apple to mature. This we believe has a most important bearing on the development of bitter pit, lesions, and will be referred to again elsewhere.

2. The Starch Test as an Indication of Picking Maturity.

It is clear from the foregoing that by staining the starch in an equatorial section of an apple we have a guide to maturity, if it can be demonstrated that maturity is indicated by the starch content. It has been shown by Bigelow, Gore, and Howard (3), Wiley (63), and Archbold (2), that the amount of starch in apples on the tree (after a certain period) or in store, falls steadily until little or none is left. Chemical analyses of Cleopatra apples at various stages of maturity were carried out for us during the present investigation by the Government Analyst. The results obtained were in accordance with those of the authorities referred to above, inasmuch as they showed a gradual falling off in starch content from the date of the first pick (6th February, 1928) to that of the last pick (12th March). Owing to the fact that for various reasons the analyses were not carried out till a variable number of days following the picking of the fruit, strictly reliable data were not obtained as to the actual composition of the fruit when picked, and we consider that no useful purpose would be served by publishing the results.

We know now that the chemical changes in picked apples are so rapid that analyses should be commenced immediately after picking. For example, Bigelow, Gore, and Howard (3) found that, "The chemical composition of apples changes very rapidly after they are picked from the trees." Working with Early Strawberry apples they observed that—

> "In six days the apples which were picked from the trees (when kept in the dark at a temperature considerably lower than that to which those remaining on the trees were exposed) contained less starch than the apples which ripened fully on the trees 43 days later. They also contained almost as high a content of invert sugar."

In carrying out the 1928 picking and storage tests for bitter pit, a sample of ten to twenty apples of each size, from each picking from the 13th February onwards, was treated with iodine. There was a general decline in the amount of starch between the apples picked on 6th February and those on 12th March. In picking the apples,

however, no attempt was made to discriminate in such a way as to secure apples as nearly as possible of comparable maturity. Rather a deliberate attempt was made to pick fruit of all available sizes and grades of maturity at each picking. Six trees were included in the experiment. The picking was chiefly from one lot of three trees, alternatively with the other three in successive weeks. As a consequence, it appears that the pick of each week was not always, as a whole, a week more mature than the apples of the preceding pick. For instance, the iodine-starch pictures showed an increase in starch content, on the whole, for the apples of 27th February as compared with those of the 20th. Subsequently it was found that, with an increase in starch content as shown by the iodine tests, there was an increased development of storage pit. An increase of starch content, as shown by iodine tests of the apples of 12th March as compared with those of 5th March, was also reflected in an increase of pit. The correlation between the starch reaction and the amount of pit developed in store was too close to be accidental.

Close examination of iodine-stained apples indicates that when the tissues within the core line are quite free from starch, and starch-free areas are well distributed throughout the flesh beyond the core line so that no large masses of starch-filled cells remain, the percentage of pit will probably not be commercially important. It appears certain that the iodine-starch reaction is a simple and effective means of recognizing the picking maturity of an apple, provided the test is made shortly after the apple is removed from the tree. The loss of starch in picked apples is so rapid that the test cannot be applied safely except to fruit at the time of picking.

3. Mechanical Pressure Tester.

Mechanical pressure testers are in use in America for the purpose of ascertaining the maturity of fruits. They have not, however, proved a reliable means of determining the picking maturity of apples. Hartman (28, page 26) states—

> "There are several factors that tend to render the pressure test inefficient as an indicator of picking maturity of apples. . . . Cultural conditions are known to produce wide differences in the texture of the fruit . . . (and) most of the softening that occurs in apples takes place following the proper time of picking."

Magness and others (39, page 23) conclude—

> "The mechanical pressure tester apparently will be of value as a measure of picking maturity for apples mainly to determine when certain varieties are becoming too soft on the trees."

A pressure tester of the type illustrated by Magness, Diehl, and Haller (40) was obtained by us from the United States of America in May, 1928. On trial, it was found that the variation between tests made on different parts of the same apple were in many cases as great as the differences between the mean tests of different apples. Comparative tests of apples made by means of both the iodine-starch reaction and the pressure-tester showed that the two failed to show constant correlation. The following results of tests at four different points around the equator of each apple will illustrate this:—

TABLE 5.—YATES APPLES.

Picked Chidlows Wells, 20th April.

Equatorial and iodine tests, 23rd April.

Apple	1.	2.	3.	4.	5.
Pressure tests in lb. ..	26·0 26·0 26·0 23·5	24·0 22·5 23·0 22·0	24·5 22·5 26·5 30·0	23·75 24·5 22·75 24·5	22·75 19·75 21·75 24·75
Mean	25·4	22·9	25·9	23·9	22·2

Apples arranged in increasing order of ripeness.

Pressure test ..	3	1	4	2	5
Iodine test	5	1	4	3	2

TABLE 6.—COMMERCE APPLES.

Picked Chidlows Wells, 20th April.

Equatorial and iodine tests, 23rd April.

Apple	1.	2.	3.	4.	5.
Pressure tests in lb. ..	18·5 22·0 21·0 17·0	22·5 24·5 20·0 20·5	25·5 30·0 22·5 24·0	22·0 21·5 23·0 22·0	17·0 18·5 22·0 15·5
Mean	19·6	21·9	25·5	22·1	18·2

Apples arranged in increasing order of ripeness.

Pressure test	3	4	2	1	5
Iodine test	3	5	2	1	4

Table 7.—Cleopatra Apples.

Picked Mahogany Creek, 20th April.

Equatorial and iodine tests, 20th April.

Apple	1.	2.	3.	4.	5.
Pressure tests in lb. ..	17·0 20·0 15·0 18·0	14·0 13·5 14·0 16·0	16·0 15·5 21·5 16·5	14·75 13·0 13·5 15·0	18·0 19·5 22·0 18·5
Mean	17·5	14·4	17·4	14·0	19·5

Apples in increasing order of ripeness.

Pressure test	5	1	3	2	4
Iodine test	5	1	2	4	3

Table 8.—Yates Apples.

Picked Karragullen, 10th April.

Equatorial and iodine tests, 16th April.

Apples	1.	2.	3.	4.	5.	6.
Pressure test in lb. ..	18·5 18·5 23·5 23·5	15·0 15·0 14·75 17·0	16·0 14·5 16·75 20·5	18·0 20·5 17·5 23·0	18·5 17·5 15·0 15·5	17·0 17·5 22·0 15·25
Mean	21·0	15·4	16·9	19·7	16·6	17·9

Apples in increasing order of ripeness.

Pressure test 1 4 6 3 5 2

Iodine test .. .. 1 2 3 and 4 not separable, 5 6

It is clear from the foregoing that the obvious defects of the pressure tester render it less reliable than the iodine test. The latter gives in one test a mean picture of the ripeness of an apple in terms of starch. The pressure test gives an idea of the softness of an apple, the accuracy of which depends upon the number of tests per fruit. This is evident from the figures given. The variation of the four equatorial tests for different parts of a single Cleopatra apple may reach as much as 6 lb., and in a Yates may exceed 7 lb. This variation in a single apple may even exceed the difference between the means of different apples. The iodine reaction has the advantage of being fool-proof, while the pressure-tester requires some care for accurate reading, as well as depending upon a spring and a dry battery, both of which depreciate with use.

Both the pressure-tester and the iodine test must be applied to the equatorial parts of the apple, as above or below the equator an apple which has not reached full maturity will be greener or riper than the mean ripeness of the apple as a whole.

In conclusion, it is evident that the mechanical pressure tester cannot be relied upon as an indicator of picking maturity. On the other hand the evidence indicates that the iodine starch test is an effective guide to maturity, provided the fruit is tested shortly after picking.

The use of the iodine test by growers appears to offer no practical difficulties. Once a competent grower has ascertained when certain apples have reached picking maturity by the iodine test, he will soon learn to use the tested specimens as standards for picking. Provided that it is realized that apples must be picked according to maturity and not size, there should be little difficulty in picking apples of approximately similar maturity relying upon the usual guides, particularly the ground-colour of the skin. The colour of the pips in our experience is not a reliable guide, but the development of the mature ground-colour, as for instance the appearance of yellow in the green of the Cleopatra, to a degree indicated by the tested apples, should prove sufficiently reliable. Where a grower is doubtful as to his ability to maintain an even grade of maturity in picking, the iodine test gives a quick and simple means of checking his work.

IX. THE CAUSES OF CORK, STORAGE PIT, AND ORCHARD PITTING.

1. Cork.

The cause of cork has yet to be fully experimentally demonstrated. Brooks and Fisher (4), however, as the result of very extensive field observations, were able to show that the occurrence of the disease varied with the character of the soil, and particularly with the water-holding capacity of the subsoil. They found also that in most districts, cork had been most serious where there was a shortage in soil-water supply, either resulting from light rainfall or a lack of irrigation. They concluded that cork is the result of fairly protracted drought conditions, specially on soils that are lacking in humus, and are not retentive of moisture. Drouth spot was considered to be the result of sudden and extreme drought conditions, rather than the more chronic but less severe conditions responsible for cork. The losses from cork were sometimes very severe, and in certain section of the Hood River Valley, Oregon, it was the cause of considerable loss annually prior to the introduction of systematic irrigation.

Rigg and Tiller (51), following the work of Mix, came to the conclusion that cork may result from any combination of circumstances

which may lead to less water entering the tree in a given time than is leaving it by transpiration during the same period. The leaves in such a case would transpire to the detriment of the apples. In this connexion the following abstracts from their paper are of great interest:—

"The marked association of trees suffering severe damage (from drought spot and cork) with soil conditions unfavorable to tree growth was an important point resulting from the present investigations. The soil conditions, whether resulting from shallow topsoil, heavy clay subsoil, hard pan, or wet substrata, all affected the normal development of the root-system of the apple trees. In such cases, the roots were frequently ill-developed and invariably lay near the surface. As a result, the trees were severely affected by sudden fluctuations in the moisture content of the soil, during times of scanty rainfall and drying winds. The shallowness of the root-system, moreover, made the trees liable to damage through severe cutting of roots by the plough and discs. The water-logged condition of the soil in wet weather, where heavy clay subsoil or hard pan occurred, likewise caused, in all probability, the death of a large percentage of root hairs responsible for supplying soil water to the trees. . . . . . The facts which have been obtained concerning the occurrence of the diseases point clearly to a deficiency of moisture as being inseparably connected with their production. Shallowness of root-system, damage to roots either by cutting or by submergence in water, lack of cultivation, bad textural qualities of the soil, bright sunshine with drying winds and a very low rainfall have all been associated with severe damage. They are all factors which operate directly or indirectly in the maintenance of low amounts of moisture in trees. In years of average rainfall, soil conditions are such as to permit normal development of fruit and foliage, but in years of low rainfall the soil factors which have been mentioned hasten the rapid drying out of the soil and a deficient supply of moisture in the trees. If the deficiency occurs at a critical time, when growth and high transpiration from the foliage are taking place, the leaves would transpire to the detriment of the apples. The experiments of Mix have shown that actual injury resembling 'cork' and 'drought-spot' can be produced in this way. . . . . . Although the cause of the disease is inseparably connected with a deficient supply of moisture, it is impossible, at the present time, to state what was the *direct cause of the death of the apple cells*."

Mix (49), discussing the cause of cork and drouth spot, states that it is evident these troubles are not two distinct diseases, but, at the most, two types of the same disease. He then goes on to consider the possibility of them being caused by parasitic fungi, bacteria or insects, spray injury, mechanical injury, or sunscald, but concludes that none of these agencies are causally related to either of the two troubles. He considers (49, p. 512) that the cause of the disease lies in the following phenomenon:—

"Chandler (8) has shown that under conditions of reduced water supply to the roots, and increased transpiration, the leaves of an apple tree may rob the green fruit of its water, causing it to wilt. This is due to the fact that the cell sap concentration in the leaves is somewhat higher than in the green fruit. Hence, the direction of the osmotic flow would then be from the fruit to the leaves. It seems probable that if cork and drought spot are due to a combination of reduced water supply and excessive transpiration, they are caused in this manner, rather than by an excessive transpiration of the fruits themselves."

Mix determined the amounts of water transpired by leaves and fruits in a given time, per unit of green weight, after detaching them from the trees. It was found that the amount of water given off by a given weight of detailed leaves was much greater than that given off by the same weight of detached fruit. Lesions resembling those of drouth spot, and occasionally those of cork, were experimentally produced by Mix (49, p. 514) following the technique established by Chandler (8):—

"Twigs bearing green fruits and leaves were detached from the tree, (the fruits and) the cut ends of the twigs . . . . were dipped in melted paraffin at a temperature low enough not to injure the tissue. These twigs were then placed in a cool, dark place, where transpiration would not be excessive. It was found that the fruits wilted and shrunk inside the paraffin, while the leaves remained quite fresh. . . . After being prepared the twigs were placed in a cool, dark place for a variable period (from 12 to 24 hours) until they had wilted to a certain point, which was learned by experience to yield the best results. The paraffin was then removed from the fruits, and the ends of the twigs freshly cut and placed in water. Except in the case of large fruits it was always possible to bring the fruits back to their original state of turgor.

The lesions began to be apparent a short time after the removal of the paraffin, or as soon as the dead tissue became oxidized; but they showed most plainly after the fruits had again become turgid. In 1916, eleven of these wilting experiments were made, involving in all 283 twigs and 449 fruits. Of these, 281 fruits developed lesions resembling those of drought spot, and varying in type from superficial to deep-seated. . . . The experiment was more uniformly successful with the smaller fruits. . . . The more rapid and severe the wilting the more the resulting injury resembled the deep-seated type of spot. . . . Less rapid and less severe wilting caused spots resembling the superficial type of lesion. . . . The spots bore the same relation to the vascular system of the fruit as in the case of natural injury. In a very few cases internal spots developed, with no external abnormality, thus resembling cork more than drought spot. . . . Microtome sections were made of some of the artificially produced spots, and these were studied in comparison with those from naturally diseased fruits. They were found to correspond with them in respect to the tissues affected, the relation of the dead spots to the vascular system, and in the nature of the injury to the cells."

In conclusion, the writer states—

"These apple diseases must be considered of a non-parasitic nature, and greatly influenced, if not caused, by a lack of sufficient moisture. . . . Since, however, in a wet season, and under conditions where there seems to be no deficiency of moisture, these diseases may occur in trees that have been previously diseased; and since there is a tendency for certain trees to become diseased year after year, insufficient soil moisture cannot be looked upon as the sole cause. Some not thoroughly understood factor or factors must operate to produce the disease under these conditions."

In connexion with the theory put forward by Mix, that "the exact method of occurrence of the injury may be by the leaves robbing the fruit of water during a critical period of low root supply and high transpiration," it is interesting to note that the blossom-end rot of tomatoes is in all probability due to a similar robbing of the fruit by the leaves during periods of insufficient water intake by the roots.

Stuckey (60) maintains that this disease "can be controlled, if not entirely prevented, by keeping an abundant supply of water in the soil." Coit and Hodgson (15) have shown that Washington Navel oranges may temporarily lose as much as 30 per cent. of their water content during the day by withdrawal of water by the leaves.

A drought spot of grapes, and a cork-like disease of certain varieties of Japanese plums (*W.A. Journ. Agric.* **3**.175.1926) in this State would also appear to be due to the withdrawal of water from the fruits by the foliage during periods of insufficient supply by the roots. It is not difficult to understand this taking place. Should insufficient water enter the plant from the roots for any length of time, for any reason whatsoever, the plant would obviously be in danger of death. In such a case the fruits being, as it were, reservoirs of moisture of lower osmotic tension would tend to lose water to the leaves. Those fruits most unfavorably situated in relation to the water entering the vascular system from the roots would be the first to suffer.

Experience in this State would indicate that blotchy cork is most common on Cleopatra trees making the most succulent growth. On reflection, it will be seen that this observation does not necessarily conflict with Mix's theory as to cork causation.

2. Storage Pit.

It is not proposed to discuss here the various theories as to the cause of bitter pit which have been put forward during the past. With the exception of the "crushed cell" theory of Herbert (31) all the theories put forward before 1927 have been reviewed by Smith (55).

It has been demonstrated elsewhere in this paper that there is a very marked correlation between the development of bitter pit in store (storage pit) and the immaturity of the fruit at the time of picking. The more immature the fruit at picking the greater the liability to pit; the less immature the fruit at picking the less its liability to pit; fruit picked when fully mature would appear to be quite free from pit-liability. It is obvious that any explanation of the origin of the bitter pit condition, unlike the theories referred to above, must be founded upon these facts.

Studies on the starch content of apples made during the present investigations have shown that there is a marked agreement in Cleopatra apples between the starch content when picked, and their subsequent liability to pit development in store. Taken alone, however, the fact that apples contain a certain amount of starch when picked means little. A case of Yates apples picked on 9th April, when containing more starch than is associated with pit-liability in Cleopatra, was quite free from pit when examined twelve weeks later. These apples had

been ten weeks in cold store, followed by two weeks room storage. Another case had been stored at room temperature for six weeks with the same result. Examination of the iodine-starch pictures presented by Yates, Granny Smith, and Cleopatra apples at various stages of maturity, revealed that there was a marked difference between these three varieties in their methods of starch disappearance. The Granny Smith apples ripened as a whole more evenly than the Cleopatras (Fig. 29), while the Yates ripened much more evenly than either (Fig. 30). In addition, whereas the Granny Smiths and Cleopatras tended to ripen in a general way outwards from the core, the Yates apples tended to ripen the zone located from the skin to a depth of 15 mm. inwards, slightly in advance of the remainder of the flesh.

In our experience, bitter pit lesions are always confined to this zone. These two facts, namely, the even maturing of Yates apples, and the maturing of the bitter-pit-zone somewhat in advance of the remainder of the flesh, are in all probability responsible for the general immunity of Yates apples from bitter pit. It is probable, also, that the liability of Cleopatra apples to pit development is directly related to the unevenness of starch disappearance in typical apples of this variety.

It has been shown in the section on the maturity of apples, that the process of starch disappearance in the flesh of the Cleopatra commences in those cells which are so located as to be as remote as possible from the various neighbouring vascular bundles. From these cells the maturation process proceeds gradually outwards, so that the last cells to lose their starch are those lying either adjacent to, or at the extremities of, the vasculars. If the maturing apple is left on the tree, and the water supply continues adequate, all the cells of the apple will eventually mature without the development of the bitter pit. The development of pit in store would appear to be due to the fact that if picked in a ripening, but still immature condition, the apple will contain insufficient supplies of water for the successful maturation of all of its cells. Those cells which first lose their starch will have first claim on the water supply of the apple, and on account of their increased osmotic suction will draw water from their less mature neighbours. These, in their turn hydrolyzing their starch, will draw water from the cells less mature adjacent to them. The process will continue in a gradual way until eventually the deficiency of water must be met by those cells along or at the extremities of the vasculars which would in the normal way be the last to lose their starch. The concentration of the cell sap, resulting from the withdrawal of water by the more mature cells, will result in the death of those cells in which the process of starch disappearance has not yet commenced, or at the most only just begun.

As suggested by Wortmann (64), the death of the cells is in all probability due to the concentration of acid in the cell sap. This explanation presupposes that the lethal concentration of sap (or acid) in the starch-filled cells is reached before the point can be attained at which their necessarily increasing osmotic suction becomes great enough to balance that of the more mature cells, thus preventing further loss of water. It is not unlikely that just as an immature Cleopatra apple as a whole contains much more acid than it does when mature (McAlpine, 2nd Vol., p. 19), so do the immature Cleopatra cells contain more acid proportionately than do the more mature ones. In other words, just as the maturation process is concerned with the disappearance of starch from the cells, it would also appear to be concerned with acid disappearance (3, 36, 44). The quite immature starch-filled cells may not, therefore, need to lose very much water to bring the acid concentration to the lethal point.

The immunity of such a variety as Yates from the development of bitter pit would seem to be quite comprehensible owing to the great evenness of the starch-disappearance process. Instead of the water deficiency having to be borne by a relatively small number of cells, as is the case in typical Cleopatra apples, the deficiency must be borne more or less evenly by all the cells of the apple. The concentration of the cell sap (or acid) in the cells is therefore unlikely to become so great as to cause their death. In the Cleopatra apples the irregularity in the maturation process necessarily leads to the last cells to mature having to stand the loss. In Yates the evenness of the maturation process simply leads in the long run to all of the cells having slightly less water content than they would have had at maturity had the apple been left to mature on the tree.

Following the death of the cells, the oxidation of the tannic acid soon leads to the browning of the dead protoplasm, and, in the course of time, to the partial browning of the cell walls (23). The withdrawal of further water from the dead cells by the surrounding healthy ones results in the collapse of some of the cell walls on to the undissolved starch grains. The tearing away of others, during the shrinking process, leads to the formation of cavities throughout the diseased area. Where located close to the surface, the shrinkage of the dead tissue causes the sinking in of the periphery, thus forming the characteristic pits. Where the necrosis extends through the hypodermal cells and includes the epidermis, the deep-chocolate-brown pits common on apples pitting in cold store are formed.

The persistence of the starch grains may be due either to the absence of diastase from the immature cells before their death, or to the inhibition of enzymatic action by the tannic acid as suggested by Ewart (24).

The discovery, mentioned elsewhere, during the present investigation, of considerable numbers of pit areas without starch grains in apples

picked prematurely and stored at room temperature (65-80°F), would appear to present an obstacle to the herein-suggested theory of pit causation. It will be remembered, however, that in every case where the pit areas were found to be free of starch grains there was no great amount of cell collapse, and only a comparatively slight amount of browning of the dead protoplasm and cell walls. The poor development of the brown colour may indicate that at the time of the death of the cells the acid content of the affected areas was lower than usual owing to the more rapid respiration at the higher temperatures, and was not sufficient to prevent the continuation after death of the process of starch hydrolysis which had in all probability already begun. In other words an acid concentration just necessary to kill the cell protoplasm at the room temperature (65-80° F.) may not necessarily be strong enough to prevent the process of starch hydrolysis at these temperatures if it has already commenced.

We have never found pit areas in cold stored apples to be free of starch. Moreover pit areas in apples which have pitted in cold store seem to retain their starch grains indefinitely, even if the apples are subsequently left for long periods at room temperatures. Dunn's apples badly pitted were obtained from cold store, 16th February, 1928. After leaving on the bench at room temperature (65-80°F) for eighteen weeks, the pitted areas still contained abundance of starch grains, although the apples had shrunk very considerably in the meantime. This would suggest that the low temperatures of the cold-store plus the inhibitory action of the high acid concentration completely destroy any enzyme originally present in the diseased cells at the time of pitting. It is, of course, well known that enzyme action proceeds very slowly at the low temperatures (33-36°F.) experienced in the cold store, and the added inhibition due to the presence of the high acid concentration may suffice to destroy the enzyme altogether in the diseased cells. Thus there would be no reason whatsoever why the starch in apples pitting in cold store should not remain in the diseased areas indefinitely, even after the apples were brought into normal temperatures.

It will be seen that our suggested explanation of the development of bitter pit in store (storage pit), agrees with that of Wortmann, promulgated as early as 1892 (64), that death is brought about by reason of the loss of water from the cells, resulting in the sap being concentrated to such a point that death ensues. It differs from Wortmann's theory in placing the emphasis as to the reason for the loss of water from the affected cells, not on transpiration, but on osmotic differences within the pulp cells of the apple, brought about or increased by the peculiar method of ripening of susceptible varieties. There is no doubt, however, that the loss of water by transpiration from the surface of the apple, following its detachment from the tree, contributes towards the development by pit reducing the total amount of water

within the apple. It is not unlikely that in susceptible varieties, pit would still occur, although not to so great an extent, if the apples were picked when rapidly ripening but still immature, even if the transpiration were completely prevented.

According to the theory put forward, the fundamental cause of pit is an insufficiency of water for the successful maturation of all the cells within the fruit. This deficiency is primarily brought about by the picking of the apples when in a ripening but still immature condition. Anything which still further tends to reduce the supply of water to the cells (such as loss of water by transpiration) or to reduce the rate of maturation (such as cold storage) will increase the liability to pit, and in the event of pit actuallv occurring, will render the lesions so much the more serious.

In connexion with the more serious lesions and the greater percentage of pit found to occur in cold stored fruit as compared with exactly similar samples stored at room temperature (60-80°F.), it is probable that while the cold storage undoubtedly greatly lessens the rate of maturation, it does not decrease, in the battery system of refrigeration in general use for fruit storage, the rate of transpiration from the fruit to anything like the same proportionate extent. Thus it is possible that in cold storage certain apples which would not have developed pit had they been stored at room temperature, may actually become pit-liable owing to the water supply decreasing by transpiration at a faster relative rate than the maturity increases. For the same reason, any pit lesions developing will be more serious than if the apples had pitted at room temperatures. At room temperatures (60-80°F.) the apples appear to lose their starch at a greater relative rate than they lose water by transpiration, thus tending to reduce the percentage pitting and the seriousness of the lesions.

Apples mature when picked do not develop pit because—(i) there is no initial water deficiency; (ii) water loss occasioned by subsequent transpiration is met more or less equally by all the cells of the fruit, and not by a relatively small number of cell groups, as in immature apples; and (iii) the acidity of the fruit tends to decrease with increasing maturity, so that even in the event of very considerable water loss by transpiration, subsequent to picking, the acid concentration does not become high enough to kill the cells.

As shown above, the liability of Cleopatra apples to the development of pit has been attributed to the great unevenness of the starch-disappearance process. Yates, which is generally considered to be immune from pit, has been shown to lose its starch very evenly. It is interesting to theorize as to why Cleopatra loses its starch in one manner while Yates loses it in another. Cleopatra is a quick-growing, relatively early-maturing apple, and field observations indicate

that, normally, its growth proceeds so long as the apple is immature on the tree. In other words, even though the apple is maturing, it is also growing somewhat at the same time. Such a condition necessitates the maturation process commencing from the cells most remote from the vasculars, and thence working gradually outwards to ensure the successful functioning of the vasculars until the maturation and growth processes are complete. Yates is a slow-growing, late-maturing variety, and develops to full size before the commencement of the maturation process. There is therefore no reason why the cells as a whole should not commence to mature more or less together, and approximately at the same rate. This phase of the question would seem to be worthy of considerable further investigation.

In connexion with the explanation of the origin of bitter pit given above, it is interesting to record certain statements in this connexion made by workers during the past.

Jaeger, 1869 (30), in the earliest known record of the disease, stated that pitting developed in liable varieties owing to the loss of water by rapid transpiration.

Wortmann, 1892 (64), considered that Stippen was due to the killing of the cells by acid, owing to the concentration of the cell sap by transpiration, following the plucking and storing of the fruit.

Zschokke, 1897 (65), agreed with Wortmann that the disease was directly or indirectly related to transpiration, and considered that unequal conduction of water in the flesh of the fruit was one of the most important factors in its causation.

Kirchner and Boltshauser, 1899 (35), stated that the disease was probably caused by the gradual loss of water by the transpiration of the fruit.

Clinton, 1903 (9), stated, "It is generally considered a physiological trouble possibly resulting from too great loss of water at these places."

Massee, 1906 (41), referring to pitted apples received from the Cape, wrote, "The disease is physiological and due to irregularities in the ripening of the fruit," but judging from his subsequent explanation, the statement would appear to have been a random one.

Güssow, 1906 (27), stated, "The causal factors are, on the one hand, rapid loss of water from the fruit, and, on the other, an inability to make good this loss with sufficient rapidity."

Scientist, 1911 (52), considered that the disease was possibly due to an accumulation of tannin or malic acid in certain spots, causing death of the cells.

Smith, 1926 (55), in reviewing the various theories of pit causation, stated—

" The occurrence of flaccid, collapsed cells in the midst of healthy turgid tissues can only be explained, on the grounds of water loss, by supposing that the osmotic pressures initially developed in these (affected) cells are so small that a fatally large amount of water is withdrawn from them before their *saugkraft* (water absorbing power) balances that of neighbouring cells. Such an eventuality may, indeed, be advanced with some degree of plausibility. The inhibition of starch metabolism, which is a normal feature of bitter pit, might result in the failure of these cells to develop a sufficiently high osmotic pressure owing to the absence of sugar."

He goes on to say, however—

" But this view assumes the impermeability of the pulp cells to sugar, which is uncertain. Ewart, indeed, found only traces of sugar in bitter pit tissue; but he states that these cells did not appear to be definitely more plasmolysable than ordinary pulp cells, and considered that they might contain some other substance exerting osmotic pressure in compensation for the absence of sugar. In brief, the theory of death by the localized drying out of cells has little evidence to recommend it, and is open to grave theoretical objections. It is more reasonable to suppose that the drying out of the cells is the result, and not the cause, of death; the more so since it is a phenomenon associated sooner or later with the death of localized patches of cells, however caused. It is seen, for example, in brown heart and in internal breakdown."

Carne, 1927 (5), stated, "Bitter pit is a necrosis of immature starch-filled tissues of rapidly-growing apples, resulting from excessive transpiration followed by osmotic action between the starch-filled cells and those in which the starch has been largely or completely changed to sugar."

3. Tree Pit and Late-formed Cork (Orchard Pitting).

As stated above, tree pit is the bitter pit which occasionally occurs in small numbers of apples while still attached to the tree. Unfortunately, owing to the limitations of symptomatology, late-formed cork cannot at times be distinguished from tree pit. This is to be regretted, but cannot be avoided. A close analogy occurs in the case of internal breakdown and brown heart.

Where an apple appears to be affected with tree pit, but is really, from a causal point of view, a case of late-formed cork, the cause is probably the withdrawal of water from the apple pulp by the leaves during periods of insufficient water intake by the roots. The affected areas are always found to be intimately associated with branches of the vascular network. The immediate cause of death would appear to be fundamentally the same as that operating in the case of bitter pit tissue, namely, the concentration of the acid in the cell sap to the lethal point by the withdrawal of water. *The difference is that whereas in cork the loss of water is probably back through the vascular tissues to the leaves, in pit the loss is from the very same groups of*

cells (namely, those alongside or at the extremities of the vascular branches), but is to the neighbouring more mature groups of cells in the pulp of the apple itself.

If these explanations are correct it is quite easy to see how it is that cork may occur any time during the growth of the apple, whereas bitter pit can only occur during the period of maturation, and is usually initiated by the mere fact of picking the apples while in a maturing but still immature condition.

It is also not difficult to imagine that under certain circumstances conditions might arise during the late life of the apples on the trees which, so far as the water supply was concerned, might closely simulate the conditions arising in apples in store after premature picking. If, for example, for any reason whatsoever, insufficient water to ensure the successful maturation of all of its cells entered the apple, while still attached to the tree, it would obviously be little better off as regards its water supply than if it had already been picked. As a matter of fact, on account of its exposure to sun and wind it might actually be worse off than if it had been picked, owing to the rapid loss of water from the surface by transpiration. Under such conditions of insufficient water supply, the same phenomena would take place in the apple as already described under the heading "The Cause of Storage Pit," and a true case of bitter pit developing in the apple while on the tree would result (i.e., tree pit). On the other hand, should the conditions become so extreme that water was actually withdrawn from the apple to supply the needs of the leaves, a condition of cork might conceivably be superimposed on the original one of pit and the pitted condition be obscured.

To summarize, then, assuming the correctness of the theory advanced, we may say that if apple cells are killed by reason of the concentration of the cell sap following the withdrawal of water by other cells of the same apple during the maturation process, we are concerned with a case of bitter pit. If the condition arises in store, we are dealing with storage pit, while, should the condition arise while the apple is still attached to the tree, with tree pit. If, on the other hand, the death of the apple cells is due to withdrawal of water by the leaves, the case is one of cork. If the necrotic lesions are purely internal we are concerned with either internal cork or crinkle cork. Internal cork commonly throws the surface of the apple into a number of smaller or larger depressions, but is not associated with surface discolouration. Crinkle cork is a special form of internal cork which is characterized by having the surface disfigured by only one, or, at the most, a very limited number, of strongly defined large deep grooves or depressions without external discolouration. Where the necrotic

tissue gives clear indication of its presence internally by means of marked surface discolouration we have either blotchy cork or drought-spot cork. Blotchy cork is characterized by the presence of numerous deep-green or brown, or mottled green and brown, depressed blotches on the surface, often accompanied by surface corrugation. Drought-spot cork is a superficial type of cork which is most commonly met with externally as a large brown stain in the skin of the fruit, giving the suggestion of a sunburn, although frequently found on fruits in a shaded position.

X. BITTER PIT OF APPLES IN RELATION TO ORCHARD PRACTICE.

The following recommendations are made for the application of the findings of this study to orchard practice:—

(i) Over-sized fruits should not be picked for export or storage owing to their strong liability to bitter pit and to internal breakdown.

(ii) Before picking for export or storage, the maturity of the fruit to be picked should be ascertained.

(iii) The following procedure is recommended for testing for picking maturity of Cleopatra apples for export or storage, and is probably effective for all other early and mid-season varieties.

Material required.—

Iodine solution (see p. 56) and a few shallow vessels.

Selection of fruit.—

Select not less than twenty typical samples of the fruit of the size grade to be picked.

Method of Testing.—

(*a*) Within one hour of picking, cut the apples in half equatorially, that is, through the centres of the cheeks. Care should be taken to prevent the cut halves from getting mixed.

(*b*) Pour the iodine solution into a sufficient number of vessels. Place the cut surface of one half of each apple in the solution and leave for one-half minute. Remove and place with treated surfaces upward. Allow to stand for three to five minutes.

(*c*) Examine the apples, taking note of the development of a blue or purple colour in the flesh. Group the apples on the following basis:—

Over-mature for picking.—No colour or practically no colour in the flesh. (Compare Fig. 33.)

Ready for picking.—Colour in the flesh in small spots scattered through the pulp outside the core line but none within the core line. Fig. 32 shows the correct reaction.

Too green for picking.—Colour in relatively large patches in the flesh; or flesh all coloured; or flesh coloured except within core line. (Compare Fig. 31.)

(iv) If less than one-half of the tested apples are ready for picking, the test should be repeated a few days later and picking delayed. When one-half of the sample apples give a satisfactory test, these should have their two halves brought together and distributed to the pickers to act as standards of maturity. Special attention should be paid to the external appearance of these standard fruits, especially the ground colour of the least-coloured parts. Each picker should be then asked to pick a few apples to standard. These should then be cut and tested to check his judgment. Once the standard has been fixed in the mind little difficulty should be found by experienced persons in picking apples of approximately the same degree of maturity. It is essential to remember that picking must be on the basis of maturity primarily and of size only secondarily. Apples accidentally or unavoidably picked from the clusters in a condition below the maturity standard should be culled by the pickers or packers from the export fruit.

(v) If apples for export cannot be placed in a ship's hold within a few days of picking, they should be cold stored and held until shipping space is available. If held in open store, in non-refrigerated trucks, or stacked on the wharf in hot weather, they are liable to become too mature and may develop internal breakdown before reaching European markets. This also applies to cold stored fruit which is removed from cold store and held in trucks or on the wharf in hot weather. Preferably the fruit should be placed in cold store at the port of shipment and loaded direct into the ship's holds.

It is realized that the adoption of the recommendations made here will shorten the picking season and introduce new problems. If shipping space is not available to take the fruit within a few days of picking, cold storage on land becomes essential to hold it in good condition. This, at least in Western Australia, would probably require a cold storage capacity far beyond that now available. Such problems are, however, beyond the scope of this paper.

XI. ACKNOWLEDGMENTS.

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XII. SUMMARY.

1. "Bitter pit" of pome fruits, in the sense used in Australia, is shown to comprise two distinct diseases, viz.:—

(*a*) True bitter pit or Stippen, a disease originating almost entirely in fruit in store and only rarely in fruit on the trees.

(*b*) Cork, a disease originating in fruit while still on the trees and never in store.

2. True bitter pit constitutes the most serious defect of Australian apples in European markets.

3. Non-parasitic spot diseases of apples in Australia are classified into Jonathan spot, cork, and true bitter pit. Each of these troubles is clearly defined.

4. Cork, originally defined by Mix, has been re-defined and extended to include four forms, namely:—

(*a*) Internal cork.—Cork proper of Mix.

(*b*) Crinkle cork.—Crinkle of McAlpine.

(*c*) Blotchy cork.—The bulk of the so-called "bitter pit" occurring on the fruits while still on the trees in Australian orchards.

(*d*) Drought-spot cork.—Superficial drought-spot of Mix.

5. Blotchy cork, the common form of cork in Australian orchards, has not previously been named or definitely recognized as at type of cork. It would appear to be not uncommon in certain districts in New Zealand, where it has been somewhat doubtfully related to the cork of American writers. It is the only form at all likely to be confused with true bitter pit, and then only in non-typical cases. It constitutes the bulk of the so-called "bitter pit" occurring in Australian orchards. In Western Australia, losses of 20-30 per cent. of the crop are not unusual in the very susceptible variety Cleopatra. The other forms of cork would appear to be relatively uncommon in Australia.

6. Blotchy cork is associated with large necrotic areas scattered through the flesh from near the surface to close to the core line. The

surface is disfigured by irregular depressions, of variable size, up to 3 x 2 cm., giving the fruit a rugose appearance. The depressions are either deep-green or brown, or mottled green and brown. This disease differs from bitter pit both macroscopically and microscopically. It has been found mainly from January until harvest time.

7. Orchard pitting is the name applied to—

(*a*) very late-formed blotchy cork in which the lesions are small and non-typical; and

(*b*) true bitter pit formed late in the life of the apples on the tree.

These two types are usually indistinguishable.

8. Storage or normal bitter pit is characterized macroscopically by few to numerous circular or subcircular pits on the surface, mainly in the calyx region of the fruit. The pits may be hardly visible externally, but more commonly average about 3 mm. in diameter, with a maximum rarely exceeding 6 mm. Associated with the pits are small necrotic areas in the flesh. These, however, may be present without surface pitting. The colour of the pit varies. It may be grey-green, olive-green, light-brown, dark-chocolate-brown, or almost black. Two forms of storage pit have been noted—(*a*) mild pit, with small rather inconspicuous surface lesions, occurring in both cold and ordinary storage; and (*b*) severe pit, characterized by relatively large pits, dark in colour, occurring only in cold-stored fruit.

9. Storage pit is shown to occur in fruit of susceptible varieties when picked in an immature condition.

10. Picking maturity and full maturity are defined. Maturation is shown to be intimately associated with starch disappearance.

11. The treatment of apples in equatorial section with iodine for starch detection is shown to be an effective means of ascertaining the maturity of apples, and directions are given which indicate how to determine, by means of the iodine-starch reaction, picking maturity, or, in other words, the degree of maturity required in apples, when picked, to ensure them subsequently maturing with good flavour and freedom from bitter pit.

12. The pressure-tester is shown to be unreliable as a guide to maturity.

13. As suggested by Mix, the probable origin of cork is the withdrawal of water from the fruits by the leaves during periods of high transpiration and insufficient water intake by the roots. Bitter pit, on the other hand, would appear to be the result of the fatal withdrawal of water during the ripening process from the more immature cells of the fruit by those in which starch hydrolysis has been almost

or entirely completed. This phenomenon appears to be confined to apples which lose their starch during the maturation process in a very irregular manner. The immediate cause of the water supply being insufficient for the successful maturation of all of the cells is, in the case of storage pit, the picking of the fruit in a ripening condition.

14. For the reduction of bitter pit to a negligible amount it is recommemnded that apples for export should not be picked until they have attained that stage of maturity herein defined as "picking maturity." They should then be placed into cold storage as soon as possible after picking. If it is not possible for the fruit to be loaded into the ships' holds within a few days, they should be kept in cold store until shipping space is available. Exposure to warm temperatures will increase the liability to internal breakdown owing to the apples tending to become too mature. The same danger will result if the apples are too mature when picked.

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XIV. APPENDIX.

I.—EVIDENCE IN ENGLISH MARKET REPORTS ON THE RELATION OF SHIPPING DATES TO BITTER PIT, JONATHAN SPOT, MOULDY CORE AND INTERNAL BREAKDOWN IN AUSTRALIAN APPLES.

A study of the reports received from selling agents in England, and from the office of the High Commissioner, reveals an apparent definite relation between the sailing dates of vessels carrying apples from Australia, and the amount of bitter pit, Jonathan spot, mouldy core, and internal breakdown found in the fruit at sale time.

It appears from Table 2 that the decrease of pit in later shipments overlap an increase of internal breakdown and mouldy core.

It should be understood that the date of sailing quoted refers only to the last port of loading. It is probable that at least part of each shipment, and that the greater part, was picked 2 to 4 or even 6 weeks before these dates. In some of the boats quoted, loadings were made in Tasmania and Western Australia and at both Albany and Fremantle in the latter State. In consequence the sailing date from Fremantle in such cases might be three weeks later than from Hobart. It would be safe to assume that the bulk of the Tasmanian fruit was picked 2 to 5 weeks, and the West Australian 1 to 3 weeks before the sailing date given. The data would indicate that for Cleopatras the best shipments from Western Australia in 1927, in respect of bitter pit and mouldy core, were those from 24th March to 2nd May, the fruit being picked probably between the second week of March and the end of April The earlier shipments had more pit, and the later more mouldy core.

From Tasmania, the best 1927 shipments appear to have been from about the middle to the end of April, suggesting that Tasmanian Cleopatras were ready for picking for export approximately 4 weeks later than in Western Australia. Considering the relative latitudes of the two States this is not surprising.

Owing to fluctuations from various causes, market prices in England cannot be used for comparison except between same varieties on the same markets. Further, the absence of scab and codling moth in Western Australian apples may have accounted for a considerable portion of the differences in prices for Cleopatra apples from Western Australia and Tasmania.

Tables 1, 2, and 3 have been compiled from press reports, and from the report of the High Commissioner's office on the 1927 season.

TABLE 1.—PRICES RECEIVED FOR CLEOPATRA APPLES IN ENGLAND.

Date of Leaving Last Port of Loading.	Ship.	Tasmania.	Western Australia.
14.3.27	*Otranto*	14s.	16s. to 18s. 6d.
25.3.27	*Largs Bay*	12s. 9d. to 15s.	15s. to 18s.
31.3.27	*Euripides*	13s. to 16s.	14s. 6d. to 18s.
8.4.27	*Hobson's Bay*	16s. 3d.	18s. 3d.
	Average for season	16s.	17s. to 17s. 9d.

It is probable that these differences are due in part to a greater amount of pit in Tasmanian apples.

TABLE 2.—BITTER PIT AND MOULDY CORE IN WESTERN AUSTRALIAN AND TASMANIAN CLEOPATRA APPLES, 1927 SEASON.

Sailing Date Last Port of Loading.	Ship.	Bitter Pit.	Maturity.
	Western Australia.		
4.3.27	*Ferndale*	Bad	Not stated
7.3.27	*Ballarat*	"	"
9.3.27	*Medic*	"	"
14.3.27	*Otranto*	Fair amount ..	"
24.3.27	*Narkunda* ..	" ..	"
25.3.27	*Largs Bay* ..	" ..	"
25.3.27	*Berwickshire* ..	Slight	"
2.4.27	*Kent*	Very little ..	Mouldy core common
5.4.27	*Berrima*	None	*Full ripe; some waste
24.4.27	*Esperance Bay* ..	"	" " "
26.4.27	*Osterley*	"	Full ripe; waste in 3-in. apples
	Tasmania.		
7.3.27	*Ballarat*	Bad	Not stated
9.3.27	*Medic*	"	"
2.4.27	*Kent*	"	"
—.4.27	*Ceramic*	Fair amount ..	"
19.4.27	*Barrabool* ..	" ..	"
—.5.27	*Benalla*	Slight	"
—.5.27	*Otaram* ..	None	Mouldy core

* It is assumed that the wastiness, recorded above, resulted from mouldy core, as in our experienc this is the principal cause of storage rot in Cleopatras.

A study of Jonathan spot on Western Australia Jonathan apples in export cargoes, based on the available information, indicates that the incidence of this disorder is similar to that of bitter pit.

TABLE 3.—JONATHAN SPOT AND INTERNAL BREAKDOWN IN WESTERN AUSTRALIAN JONATHAN APPLES.

Date of Leaving Last Port of Loading.	Ship.	Jonathan Spot.	Maturity.
4.3.27	*Ferndale*	Not reported ..	Immature
7.3.27	*Ballarat* ..	Bad	Good
24.3.27	*Narkunda* ..	Fair amount ..	"
25.3.27	*Largs Bay* ..	Slight	"
2.4.27	*Kent*	Not mentioned ..	Fully ripe; breakdown in large fruit
5.4.27	*Berrima*	" ..	Wasty
8.4.27	*Hobson's Bay* ..	" ..	Fully ripe; becoming wasty
18.4.27	*Mooltan*	" ..	Wasty
5.5.27	*Moreton Bay* ..	" ..	Breakdown

This would indicate that the best shipments were those from 25th March to 2nd April. Such fruit was probably picked during the first three weeks of March.

The evidence available in regard to Jonathan spot on Tasmanian Jonathans is very limited, references being made to it only in one shipment—*ex Cathay*

sailing from Fremantle on 4th April. Shipments, *ex Esperance Bay, Osterley,* and *Themistocles* sailing from the same port on 24th-26th April were stated to be over-ripe and wasty.

Since writing the above, a report has come to hand on "The Nature and Prevention of Wastage in Australian Fruit imported into England," by Dr. J. Barker, of the Low Temperature Research Station, Cambridge. This report, dealing with shipments in 1927, is so important that portions are reproduced as follows :—

2. Apples.

"*Details of Survey.*

Wastage has been chiefly due to two diseases, bitter pit and internal breakdown, and of these bitter pit has caused the more serious losses in fruit on arrival at the Docks.

The actual figures for wastage due to these two diseases for the various varieties throughout the season are given in Table 1.

Table 1.—Percentage wastage for different varieties due to Bitter Pit and Internal Breakdown in all samples examined during the 1927 season.*

Tasmania.			Western Australia.		
Variety.	% Bitter Pit.	% Internal Breaktown.	Variety.	% Bitter Pit.	% Internal Breakdown.
Adam's Pearmain	2.0	2.0	Cleopatra ..	18.0	0.2
Alfriston ..	2.0	2.0	Dunn's Seedling	0.5	0.0
Cleopatra ..	10.0	0.2	Granny Smith ..	7.0	0.0
Cox's Orange Pippin	21.0	4.0	Jonathan ..	4.0	5.0
Dunn's Seedling ..	7.0	2.0	Rokewood ..	1.0	0.0
Jonathan ..	1.0	3.0	Rome Beauty ..	2.0	0.0
King Pippin ..	0.0	2.0			
Ribston Pippin ..	9.0	3.0			
Scarlet Pearmain..	1.0	0.3			
Sturmer Pippin ..	9.0	0.1			

It will be seen that the occurrence of bitter pit has been of significant extent in Cox's Orange Pippins, Cleopatras, Ribston, and Sturmer Pippins from Tasmania, and in Cleopatras from Western Australia.

Internal breakdown has been less extensive in fruit on arrival at the Docks than bitter pit, but this disease may actually be responsible for equally serious, if not greater, wastage since the further wastage during the period of distribution and consumption appears to be unexpectedly rapid. Examples of this deterioration are given in the next section. At this stage it will suffice to state that the varieties most susceptible to internal breakdown are Jonathans, from both Tasmania and Western Australia, and Cox's Orange Pippins, and Ribston Pippins from Tasmania.

The Dock examination data for successive shipments throughout the season are on the whole in agreement with the accepted generalizations that bitter pit is much more extensive in the early shipments of each variety, and that both bitter pit and internal breakdown are more severe in the larger apples of each variety. There is also some indication that internal breakdown increases in the later shipments of the susceptible varieties, and is more liable to occur in apples which are yellow in colour on arrival than in fruit which is less ripe.

* These figures were obtained in the routine examination of shipments of fruit on arrival at the Docks conducted by the Empire Marketing Board. A full account of this work is given in Special Report No. 3 of the Empire Marketing Board.

The wastage due to fungal rotting is relatively small—under 1 per cent. for all varieties throughout the season—and appears to be due mainly to mould attack following accidental skin injuries due to bruising, &c.

Jonathan spot was observed in both Western Australian and Tasmanian Jonathans, but the proportion was significant (9 per cent.) only in the case of the former.

In addition to the above types of deterioration, severe freezing was found in several hundred cases in two shipments, and in one shipment, brown heart was present.

Wastage During Period of Distribution and Consumption.

The inaccurate nature of the market salesman's examinations and the shortness of the period for which fruit normally remains in the warehouse make it unwise to attach much importance to market reports of rapid wastage, following unloading. Nevertheless it should be mentioned that Tasmanian Cox's Orange and Ribston Pippins and Western Australian Jonathan apples were often reported as showing very rapid wastage due to internal breakdown. This wastage was particularly noticeable in large apples.

Actual observations of the rate of development of internal breakdown were made upon three boxes—one of Cox's Orange Pippins and two of Ribston Pippins. The boxes were selected as showing a small proportion of breakdown on arrival in the market. The figures for development of internal breakdown in these cases are given in Tables 2, 3, and 4, and indicate a surprisingly rapid rate of deterioration. If such deterioration is typical of a significant proportion of the marks of these varieties, then the total wastage due to internal breakdown must be heavy.

It is clearly most desirable that further information on this point should be obtained, and it is accordingly proposed to adopt the method of keeping boxes under observation in the laboratory in order to make a fairly exhaustive study, during the coming season, of the deterioration following unloading in the varieties susceptible to breakdown.

Table 2. 2½″ Cox's Orange Pippin, Collinsdale—

Days from discharge	5	10	18	30
Internal breakdown	0.7%	12.8%	25.0%	33.8%

Table 3. 2½″ Ribston Pippin, Latrobe—

Days from discharge	3	9	18
Internal breakdown	4.0%	20.5%	38.5%

Table 4. 2½″ Ribston Pippin, Tasmania—

Days from discharge	6	19
Internal breakdown	2.5%	16.5%

In the market, it is often stated that bitter pit develops rapidly after the apples reach the market. From experimental work on this point, however, this statement appears to be correct only in the sense that the surface pitting becomes more prominent, but not in its suggestion that surface pitting appears in fruit which is free from pitting on arrival at the market. Thus, in Tasmanian Cleopatra apples kept in the laboratory no fresh occurrence of bitter pit in sound apples was noted, even after several weeks, but the affected apples showed an increase in the severity of the pitting.

Australian apples are accordingly not likely to acquire a reputation for rapid deterioration because of the development of bitter pit after leaving the ship. This reputation may, however, attach with some justice to certain varieties, if the development of internal breakdown in apples, apparently sound when unloaded, is as rapid as would appear to have been the case during the 1927 season.

Significance of Results of Survey.

From the above account of wastage in Australian apples it will be evident that the reduction of the amount of wastage in the fruit on its arrival at the market depends almost entirely on ability to control the development of the two diseases, bitter pit and internal breakdown.

Bitter Pit.

It has long been known that bitter pit is much more extensive in early than in later shipments, but according to the information available here, experimental evidence of the relation between development of bitter pit and maturity of picking is still inadequate. Similar uncertainty apparently prevails with regard to the effect of the temperature of storage, or of delay before storage on the development of bitter pit.

In view of the great importance of such knowledge to the Australian apple industry, and the fact that this knowledge could be readily obtained by relatively simple experimentation in Australia (the irregularity of the occurrence of the disease in England renders it impossible to carry out investigation work here), it is very striking that the published work on bitter pit in Australia is so limited in extent, and so inconclusive in character.

Internal Breakdown.

The fact that internal breakdown is responsible for considerable losses in certain varieties on arrival at the Dock, and that the further wastage due to this type of deterioration after unloading may be of very serious extent, appears not to have been fully realized hitherto. This position is undoubtedly largely attributable to the salesmen's inability to diagnose accurately any type of deterioration other than bitter pit. A study of the salesmen's report on wasty samples of fruit has shown that the condition of internal breakdown is either described as " chilled," " frozen," or " frosted," or antithetically as " over-ripe and wasty." This latter description is often applied to apples which are green in colour, and are definitely not over-ripe, but subject to internal breakdown.

As as consequence of this inaccurate identification* of wastage, little reliable information is available of the factors determining the development of internal breakdown in Australian apples. The utility of such knowledge may be shown by a brief consideration of internal breakdown as it is known in English and American apples. In these apples there appear to be two distinct types of internal breakdown—

(i) *Low Temperature Type.*—This is a disease of cold storage developing earlier in storage at 34 degrees than at 38 degrees F.; the onset in storage is little affected by maturity at picking. This type of breakdown has been observed in English Bramley's, Lanes, &c., and in the Californian Yellow Newtown.

(ii) *Jonathan Type.*—This is a disease which occurs at all temperatures. It may occur on the tree, and is definitely related to the maturity of the fruit when picked, being liable to occur in fruit left on the trees after a certain stage. The onset in storage is longer delayed the lower the storage temperature.

It will be seen that the preventive measures to delay the onset in storage differ for the two types. A knowledge of the types of breakdown which occur in the varieties of Australian apples liable to wastage by breakdown on the overseas market is thus of great importance.

* Since such inaccurate identifications must tend to bewilder the research staffs and growers in Australia, it may be desirable that steps should be taken to secure reports which are scientifically reliable of the condition of fruit on arrival in the market.

It is suggested that the determination of the effect of temperature of storage and of maturity at picking on the development of internal breakdown should be made the first objective of a comprehensive investigation, in which would also be included the study of the other factors, orchard, &c., known to influence breakdown. In this investigation, special attention should be given to the development of breakdown after removal from storage because of the importance of this aspect in the overseas market.

The wide difference in the effect of the temperature of storage on the development of the different types of breakdown is of special significance in connexion with transport to the overseas market, since it is known that large differences in temperature and in rates of cooling occur in different parts of the hold. It may be desirable to test the effect of these differences of temperature on the condition of the fruit on arrival and during a period of several weeks after unloading, by placing experimental consignments of comparable fruit in different parts of the hold. For these experimental consignments, the varieties of apple susceptible to internal breakdown—Cox's Orange Pippin or Ribston Pippins from Tasmania and Jonathans from Western Australia—would probably be the best material to use. The experiments would be made more complete if thermographs were placed with the experimental fruit so that a definite record of the temperature was obtained.

The markedly greater wastage in large, as compared with medium, sized apples raises the question of restricting the export of the large-sized apples. Close attention will accordingly be given in England to the relation between size and wastage during the season."

It is interesting to note how closely Dr. Barker's report confirms the findings of this paper. Of particular importance is the statement that "wastage has been chiefly due to two diseases, bitter pit and internal breakdown, and of these, bitter pit has caused the most serious losses in fruit on arrival at the Docks." This is supported by a circular issued by Messrs. F. W. Moore and Co. Ltd., agents, in London, entitled "Australian and New Zealand Fruit. Review of 1926 Season," published in August, 1926. They state in reference to bitter pit, "as far as our own experience extends, this is much the worst evil orchardists have to fear."

II.—EVIDENCE OF LOSS FROM PIT IN WESTERN AUSTRALIAN APPLES 1928 SEASON.

The following figures are based upon the returns supplied by Inspectors under the Customs Act, in regard to lines rejected because of bitter pit. Much of this fruit was examined by the senior author in cold store, or on the wharf at Fremantle. In all cases seen, the fruit was definitely affected with pit. The rejections from fruit submitted for s.s. *Tekoa* and *Tritonia* were mainly for the extreme type of cold storage pit.

TABLE 4.—REJECTIONS FOR BITTER PIT, FREMANTLE AND ALBANY, 1928 SEASON.

Vessel.	Date Sailing from Fremantle.	Variety.	Rejected Cases.	Total Shipment Cases.
Tekoa	18.2.28	Cleopatra	521	23,079
		Dunn's	75	
(Agents reported: Fruit immature and very green. Cleopatra's badly pitted.)				
Tritonia	22.2.28	Jonathan ..	87	1,900
Berrima	3.3.28	Cleopatra	146	7,606
		Jonathan	8	

TABLE 4—*continued.*

Vessel.	Date Sailing from Fremantle.	Variety.	Rejected Cases.	Total Shipment Cases.
	(Agents reported: Apples spotted.)			
Port Huon	20.3.28	Cleopatra	1,603	61,201
		Cox's	15	
		Jonathan	20	
		Miscellaneous ..	40	
	(Agents reported: Generally good, but pit in evidence.)			
Port Brisbane ..	25.3.28	Cleopatra	349	23,149
		Jonathans, Dunn's, and Cleopatra's	33	
Otaki	30.3.28	Cleopatra	193	20,032
City of Palermo ..	4.4.28	Cleopatra	29	2,050
		Dunn's	169	
Moreton Bay ..	5.4.28	Dunn's	20	158
			3,308	139,175

The above table takes no note of apples discarded for cork in the orchard, apples passed out for cork and pit by Inspectors at the two principal apple centres, Bridgetown and Mt. Barker; or of apples withdrawn by agents at the ports and not submitted for shipment. It should also be realized that lines very slightly pitted, *at the time of inspection on the wharf*, would be passed by Inspectors as fit for export.

No definite evidence is available as the extent to which prices of Western Australian apples in Europe were affected by the presence of pit. An agent's report from Hamburg, published in the press, in reference to Australian apples (not Western Australian) stated that Cleopatras, *ex Horatio*, sold at 16s. to 20s. for clean fruit, and 12s. to 16s. for pitted fruit.

Agents' reports in reference to the *Port Huon* shipment—the largest of the season from Western Australia—indicated, from the prices quoted that the fruit was in very variable condition. Pit was stated to be in evidence and Jonathans, more or less, over-ripe. The prices were Cleopatras 9s. to 19s. 9d., Dunn's 11s. to 21s. 6d., and Jonathans 6s. 6d. to 16s. 6d. It would appear probable that this extraordinary range of prices in the same shipment was due to pit in Cleopatra and Dunn's and to over-ripeness in Jonathans.

It will be noted that the bulk of the rejected cases were Cleopatras with Dunn's next. This is interesting because, while Cleopatra is recognized in Australia as very pit (including cork) liable, Dunn's are stated to be rarely affected (McAlpine 43, and Darnell-Smith, 17.).

In some of the cases examined upwards of 100 per cent. of the fruit was badly affected with deep chocolate-coloured pits; in many fruits extending over most of the surface. This fruit had been picked between the middle and the end of January, about one month before the usual time. This was probably due to the then large size of the fruit, which, owing to the small crop, promised to become over-sized for shipping. After picking it was placed in cold store at Fremantle awaiting shipment by the s.s. *Tekoa* and *Tritonia* in the third week of February. Eight consignments of these apples were traced, consisting of two of Dunn's (99 cases), three of Jonathans (87 cases), and three of Cleopatras (335 cases). All of these were rejected or withdrawn because of pit. In several cases the same varieties from the same orchards were picked later and consigned direct to the ship's side without cold storing. These were passed by the Inspectors, no pit being noticed just prior to loading. Agents' reports from Germany show that the Cleopatras *ex Tekoa* subsequently became badly pitted.

EXPLANATION OF FIGURES.

Plates.

Fig. 1.—Severe storage pit on Cleopatra. (Note deep chocolate-brown colour of many of the pits.) (Frontispiece.)

Fig. 2.—Blotchy cork on Cleopatra. (Note the mottled deep green and brown irregular blotches disfiguring the surface.) (Frontispiece.)

Fig. 3.—Jonathan spot on Esopus Spitzenberg. (Note fungal infection following Jonathan spot in apple on left).

Fig. 4.—Internal cork on Beurre Bosc Pear. (Note large cork areas in the flesh).

Fig. 5.—Crinkle cork " pig face " type (after McAlpine). (Note absence of surface discolouration.)

Fig. 6.—Blotchy cork on Cleopatra. (Note irregular depressed surface blotches).

Fig. 7.—Blotchy cork on Cleopatra. (Note extensiveness of the lesions).

Fig. 8.—Blotchy cork, mild pit and severe storage pit on Cleopatra.

Fig. 9.—Cleopatra apples affected with blotchy cork (left), mild storage pit from open store (middle) and severe storage pit from cold store (right).

Fig. 10.—Section of blotchy cork tissue on Cleopatra x 96. (Note thickness of cell walls, great abundance of brown amorphous material and disappearance of starch in the affected cells).

Fig. 11.—Section of storage pit tissue in Cleopatra x 96. (Note persistence of starch grains and absence of thickening of the cell walls in affected cells. Note also vascular bundle).

Fig. 12.—Blotchy cork on Sturmer Pippin.

Fig. 13.—Internal lesions of blotchy cork on Sturmer Pippin.

Fig. 14.—Section of Sturmer affected with blotchy cork. (Note lack of compactness of lesions and obvious association of lesions with vasculars).

Fig. 15.—Internal lesions of blotchy cork on Esopus Spitzenberg. (Note large compact lesions and the presence of necrotic areas close to the core).

Fig. 16.—Tasma apples showing drought-spot cork.

Fig. 17.—Tasma apple. Cork associated with water-core.

Fig. 18.—Jonathan spot on Jonathan.

Fig. 19.—Orchard pitting on Granny Smith.

Fig. 20.—Severe storage pit on Dunn's (left) and Cleopatra (right) from cold store.

Fig. 21.—Internal lesions of mild storage pit on Cleopatra (from cold store).

Fig. 22.—Internal lesions of severe storage pit on Cleopatra (from cold store). (Note the term " severe " applies only to the seriousness of the external pitting and not to the abundance of seriousness of the internal lesions).

Fig. 23.—Deep-seated bitter pit lesion in Cleopatra apple x 96. (Note presence of persistent starch grains in affected cell but absence from healthy cells).

Fig. 24.—Section of Cleopatra apple with storage pit x 96. (Note persistence of starch grains in the affected cells).

TEXT FIGURES.

FIG. 3.—JONATHAN SPOT ON ESOPUS SPITZENBERG.

(Note fungal infection following Jonathan spot in apple on left.)

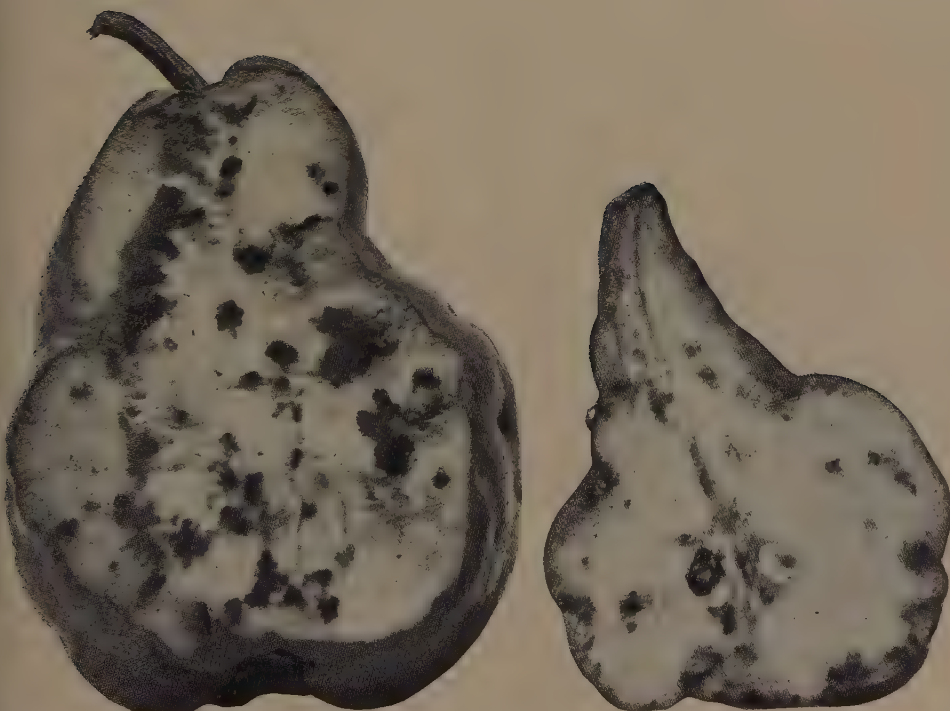

FIG. 4.—INTERNAL CORK ON BEURRE BOSC PEAR.

(Note large Cork areas in the flesh.)

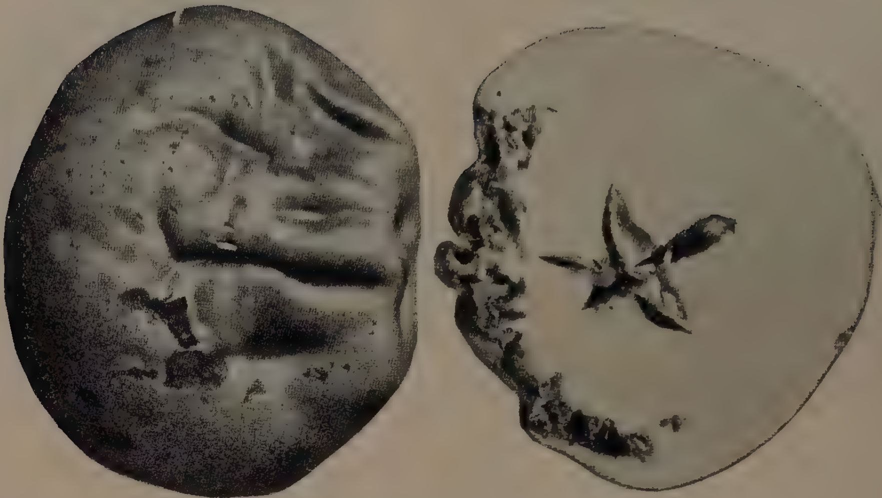

FIG. 5.—CRINKLE CORK, "PIG FACE" TYPE (after McAlpine).
(Note absence of surface discoloration.)

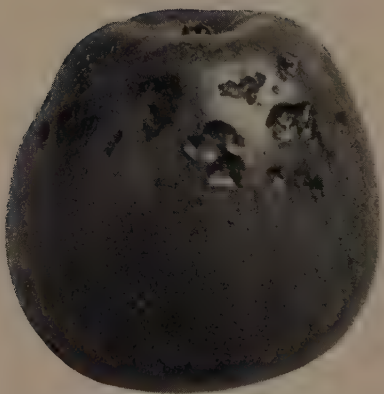

FIG. 6.—BLOTCHY CORK ON CLEOPATRA.

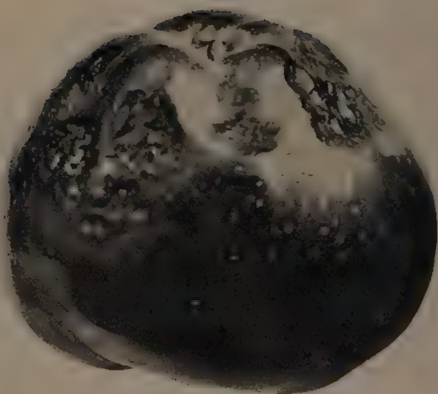

FIG. 7.—BLOTCHY CORK ON CLEOPATRA.

Fig. 8.—Blotchy Cork, Mild Pit, and Severe Storage Pit on Cleopatra.

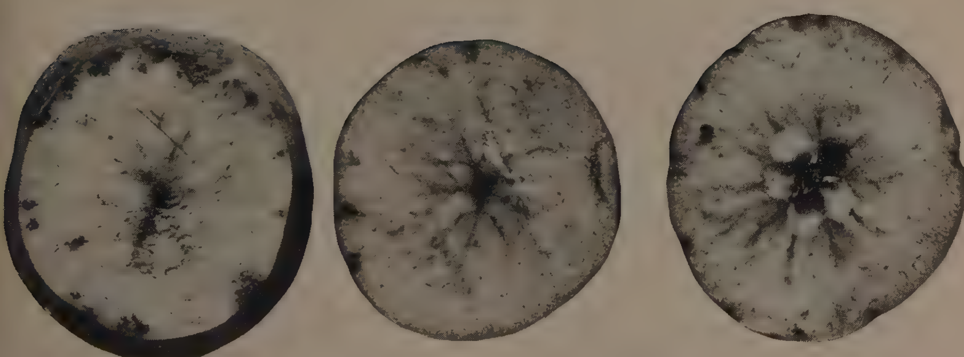

Fig. 9.—Cleopatra Apples affected with Blotchy Cork (left), Mild Storage Pit from open Store (middle), and Severe Storage Pit from Cold Store (right).

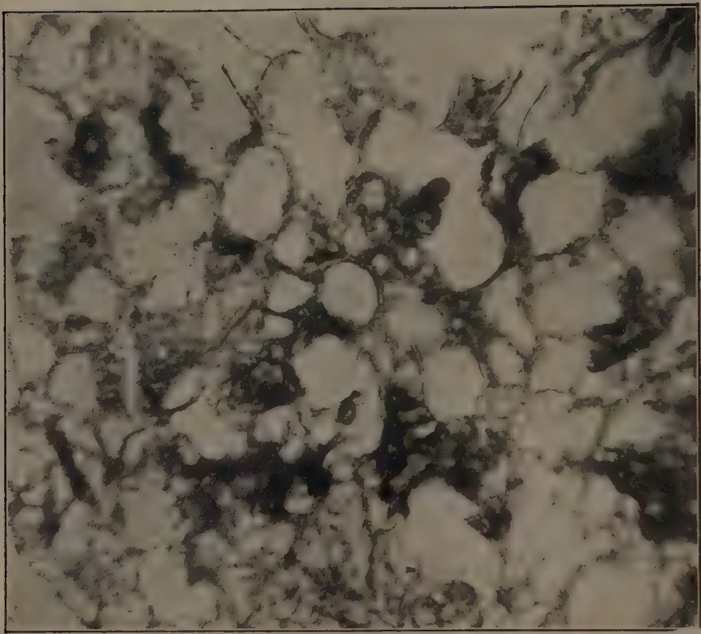

FIG. 10.—SECTION OF BLOTCHY CORK TISSUE ON CLEOPATRA. x 96. (Note thickness of cell walls, great abundance of brown amorphous material, and disappearance of starch in the affected cells.)

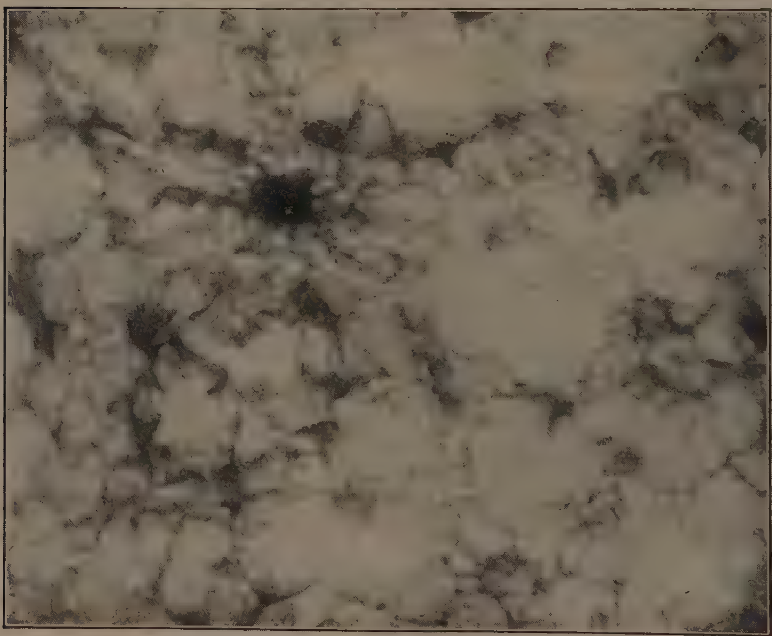

FIG. 11.—SECTION OF STORAGE PIT TISSUE IN CLEOPATRA. x 96. (Note persistence of starch grains and absence of thickening of the cell walls in affected cells. Note also vascular bundle.)

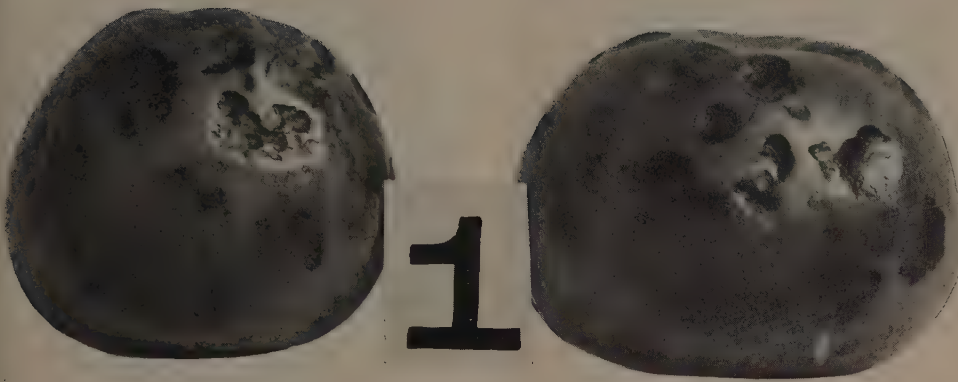

Fig. 12.—Blotchy Cork on Sturmer Pippin.

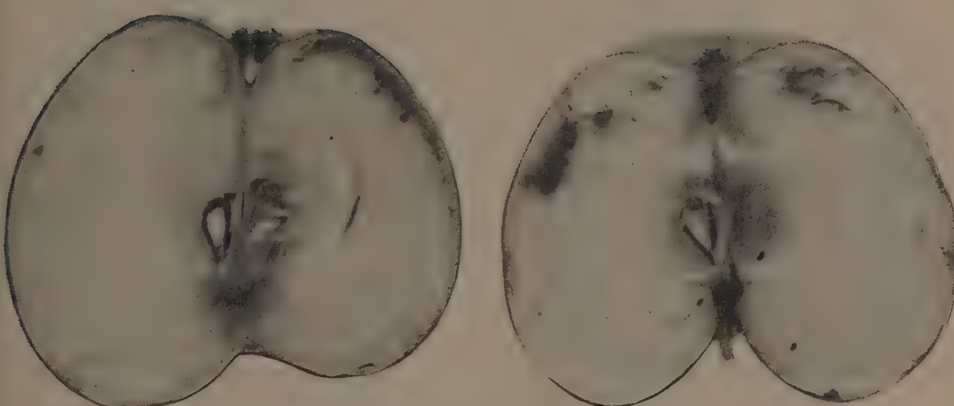

Fig. 13.—Internal Lesions of Blotchy Cork on Sturmer Pippin.

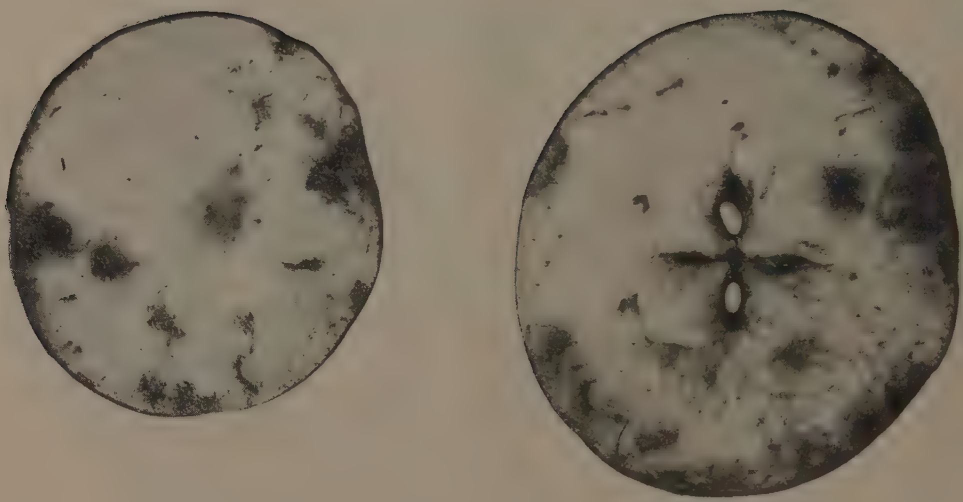

Fig. 14.—Section of Sturmer affected with Blotchy Cork.

(Note lack of compactness of lesions and obvious association of lesions with vasculars.)

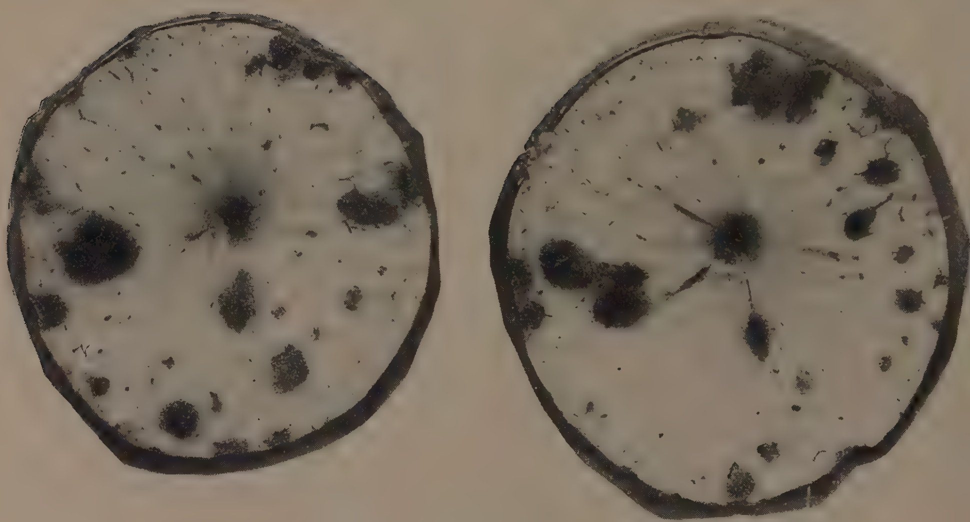

Fig. 15.—Internal Lesions of Blotchy Cork on Esopus Spitzenberg.

(Note large compact lesions and the presence of necrotic areas close to the core.)

Fig. 16.—Tasma Apples showing Drought-spot. Cork.

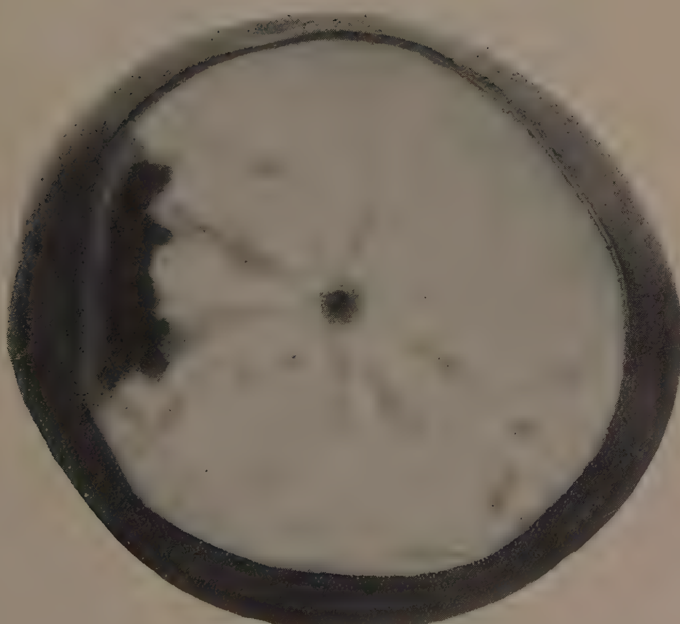

Fig. 17.—Tasma Apple. Cork associated with Water Core.

Fig. 18.—Jonathan Spot on Jonathans.

Fig. 19.—Orchard Pitting on Granny Smith.

FIG. 20.—SEVERE STORAGE PIT ON DUNN'S (LEFT) AND CLEOPATRA (RIGHT). (FROM COLD STORE.)

FIG. 21.—INTERNAL LESIONS OF MILD STORAGE PIT ON CLEOPATRA. (FROM COLD STORE.)

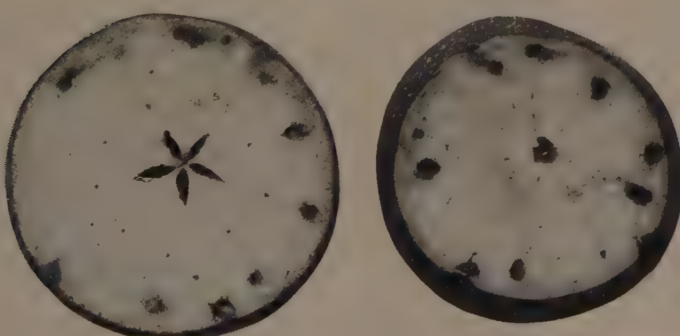

FIG. 22.—INTERNAL LESIONS OF SEVERE STORAGE PIT ON CLEOPATRA. (FROM COLD STORE.)

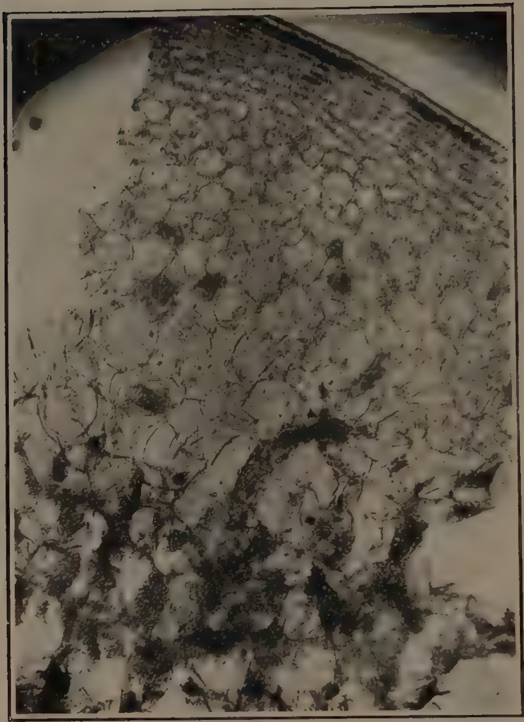

Fig. 23.—Deep-seated Bitter Pit Lesion in Cleopatra Apple. x 96.
(Note presence of persistent starch grains in affected cells, but absence from healthy cells.)

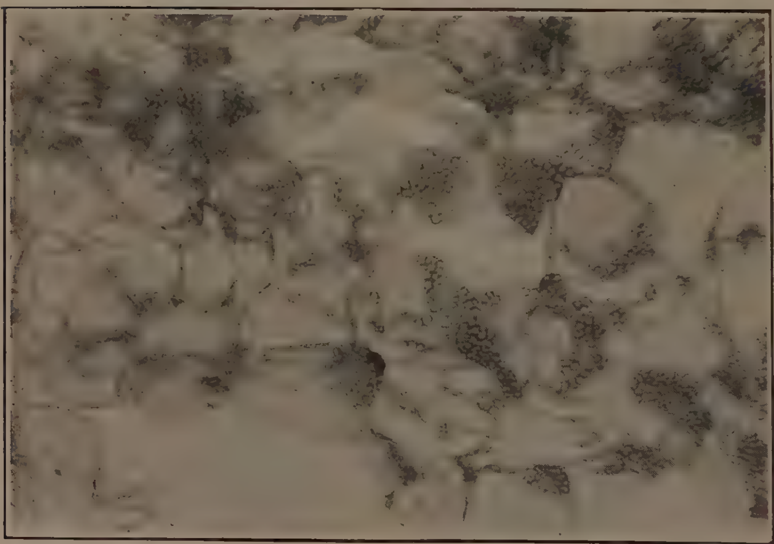

Fig. 24.—Section of Cleopatra Apple with Storage Pit. x 96.
(Note persistence of starch grains in the affected cells.)

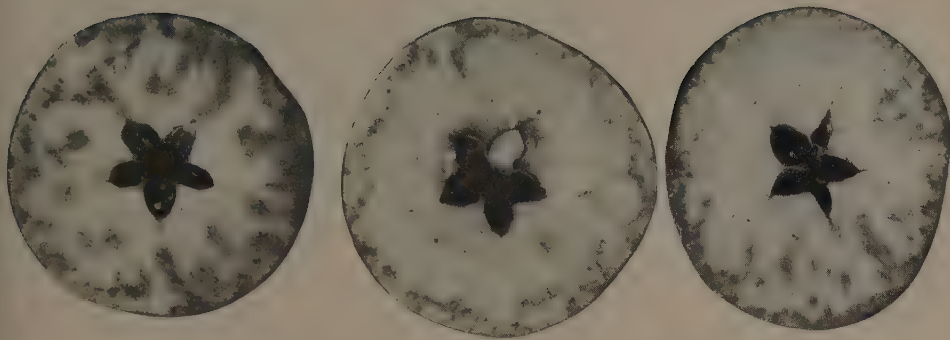

Fig. 25.—Starch Reaction of Medium-sized Cleopatra Apples.
Picked 5th March, 1928. Photographed 7th March, 1928.

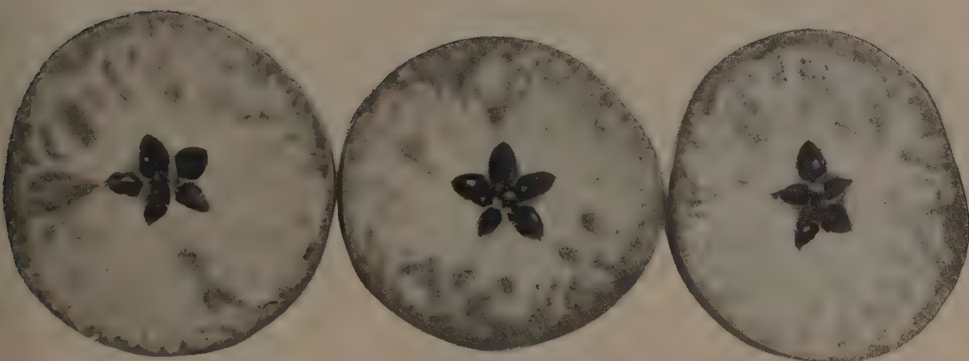

Fig. 26.—Starch Reaction of Large-sized Cleopatra Apples.
Picked 5th March, 1928. Photographed 7th March, 1928.

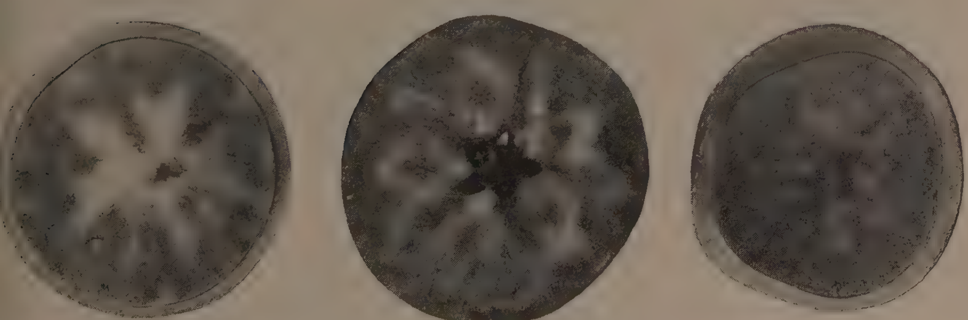

Fig. 27.—Iodine-Starch Reaction, Pedicel, Equatorial and Calyx Regions of same Cleopatra Apple.

Fig. 28.–Iodine–Starch reaction. Longitudinal Sections of Three Cleopatra Apples showing Starch Loss proceeding in a General Way from Pedicel to Calyx Region.

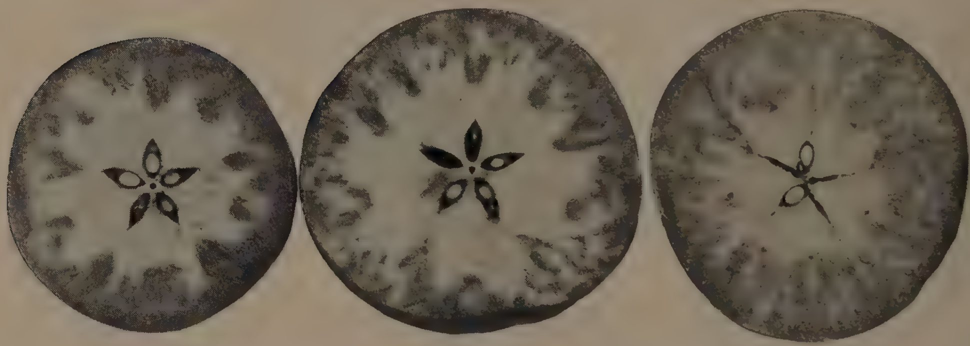

Fig. 29.—Iodine–Starch Reaction. Granny Smith Apples.
Picked 5th March, 1928. Photographed 7th March, 1928.

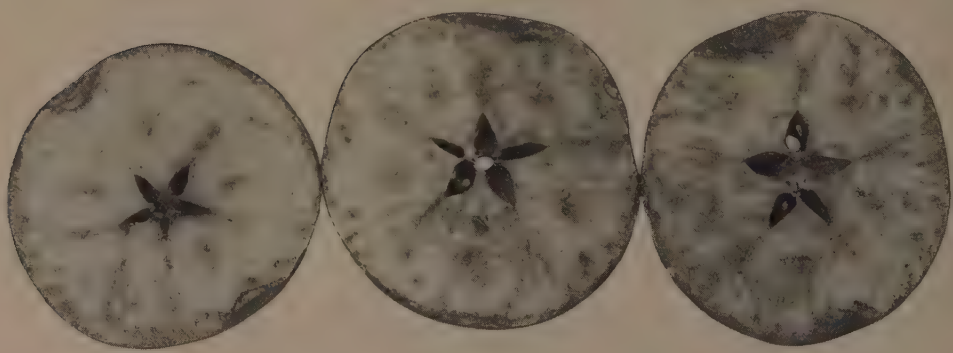

Fig. 30.—Iodine–Starch Reaction. Yates Apples.
Picked 9th April, 1928. Photographed 17th April, 1928.
(Note great evenness of starch disappearance.)

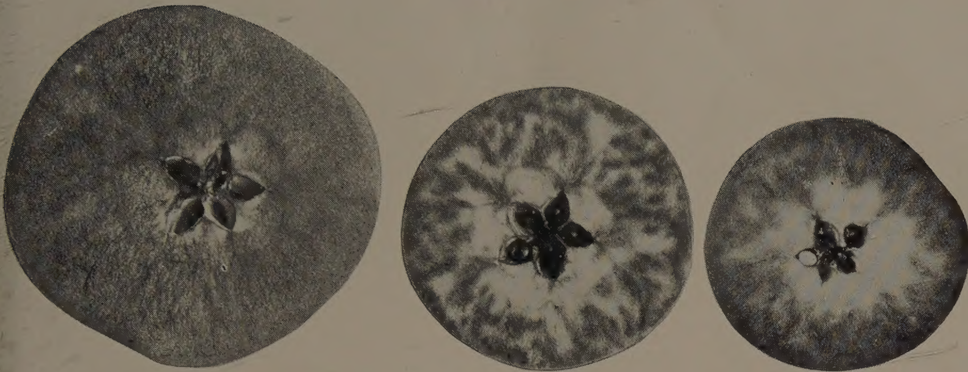

Fig. 31.—Iodine-Starch Reaction of Cleopatra, showing Apples too Immature for Picking for Export.

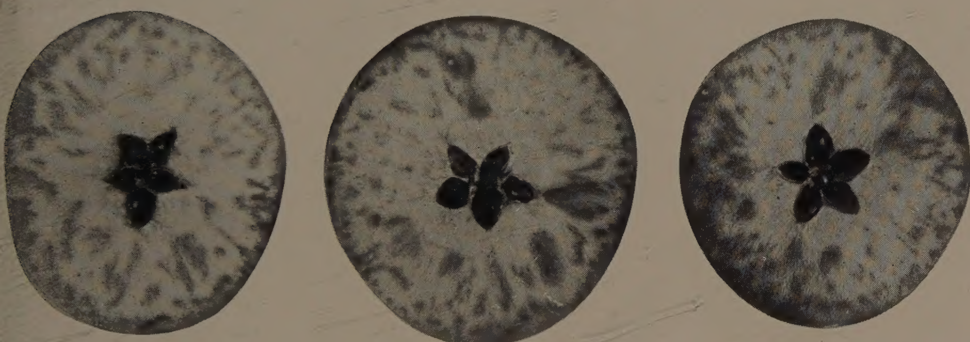

Fig. 32.—Iodine-Starch Reaction of Cleopatra, showing Apples at Correct Maturity for Picking for Export.

Fig. 33.—Iodine-Starch Reaction of Clepoatra, showing Apples too Mature for Picking for Export.

(The apple on the right is only just too mature for picking for export, having somewhat too little starch in the upper right-hand portions, although elsewhere being satisfactory).

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BULLETINS

have been issued

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36. Kimberley Horse Disease
37. Paper Pulp and Cellulose from the Eucalypts by the Sulphite Process
38. The Chemical Composition of Wool, with especial reference to the Protein of Wool-fibre (Keratin)
39. The Utilization of Sulphur by Animals, with especial reference to Wool Production
40. Observations on the Hydatid Parasite (Echinococcus granulosus) and the Control of Hydatid Disease in Australia
41. Studies concerning the so-called Bitter Pit of Apples in Australia